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Part V

ROTOR-BEARING DYNAMICS DESIGN TECHNOLOGY
Part V: Computer Program Manual for Rotor Response and Stability

J. W. Lund

Mechanical Technology Incorporated

TECHNICAL REPORT AFAPL-TR-65-45, PART V

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Air Force Aero Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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FOREWORD

This report was prepared by Mechanical Technology Incorporated, 968 Albany-Shaker Road, Latham, New York 12110 under USAF Contract No. AF 33(615)-1895. The contract was initiated under Project No. 3145, "Dynamic Energy Conversion Technology" Task No. 314511, "Nuclear Mechanical Power Units." The work was administered under the direction of the Air Force Aero Propulsion Laboratory, Research and Technology Division, with Mr. John L. Morris (APFL) acting as project engineer.

This report covers work conducted from 1 April 1964 to 1 April 1965.

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The assistance of Miss Joyce A. Freeman, Mr. Kenneth W. Bauman, and Mr. Ralph S. Graham of the Digital Computation Division (SESCD) at Wright-Patterson Air Force Base during the review and final preparation of the computer programs is gratefully acknowledged.

This technical report has been reviewed and is approved.

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ABSTRACT

This report is a manual for using the two computer programs:

1. "Unbalance Response of a Rotor in Fluid Film Bearings"
2. "The Stability of a Rotor in Fluid Film Bearings"

The report gives the analysis on which the programs are based, and the instructions for preparing the computer input and for interpreting the computer output.

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ILLUSTRATIONS

SYMBOLS

A	Cross sectional area of shaft, in^2
a,b	Major and minor axis of ellipse, in (or: lbs, lbs.in)
a_n,b_n,c_n,d_n	Influence coefficients for shaft section, see Eqs.(4) to (7)
C	Radial bearing clearance, inch
$C_{xx},C_{xy},C_{yx},C_{yy}$	Bearing damping coefficient for translatory whirl, lbs.sec/in
$D_{xx},D_{xy},D_{yx},D_{yy}$	Bearing damping coefficients for conical whirl, lbs.in.sec/radian
E	Youngs modulus, $lbs.in^2$
a	Rotor mass eccentricity, inch
F_x,F_y	x-and y-components of bearing reaction, lbs.
I	Cross-sectional moment of inertia of shaft, (I_n between stations n and (n+1)), in^4
I_P	Polar mass moment of inertia of a rotor mass, $lbs.in.sec^2$ (in input: $lbs.in^2$)
I_T	Transverse mass moment of inertia of a rotor mass, $lbs.in.sec^2$ (in input: $lbs.in^2$)
$K_{xx},K_{xy},K_{yx},K_{yy}$	Bearing spring coefficients for translatory whirl, lbs/in.
K_r	Rotor stiffness, lbs/in
L_n	Length of shaft section between station n and (n+1), inch
L	Bearing length, inch
l	Rotor length, inch
M	Bending moment (M_n to the left, M_n' to the right of station n), lbs.in.
M_x,M_y	x and y-components of pedestal mass, $lbs.sec^2/in$ (in input: lbs).
M_T	Total rotor mass, $lbs.sec^2/in$
$M_{xx},M_{xy},M_{yx},M_{yy}$	Bearing spring coefficients for conical whirl, lbs.in/radian
m_n	Mass at rotor station n, $lbs.sec^2/in$ (in input: lbs)
P_x,P_y	x and y-components for force transmitted to base, lbs.

t	Time, seconds
U_x, U_y	Cosine and sine-components of unbalance, lbs.sec^2 (in input: oz.in)
V	Shear force (V_n to the right of station n), lbs.
W	Bearing reaction, lbs.
x, y	Components of the rotor amplitude, inch (in output: mils)
z	Coordinate along length of rotor, inch.
α	Phase angle between amplitude radius vector and unbalance see Fig. 5, radians
β	Angle between major axis and x-axis, see Fig. 5, radians
δ_x, δ_y	Pedestal damping coefficients for conical whirl, lbs.in.sec/rad.
θ, φ	$= \frac{dx}{dz}, \frac{dy}{dz}$, components of the slope of the deflected rotor, rad.
$\varkappa_x, \varkappa_y$	Pedestal spring coefficients, lbs/in.
σ_x, σ_y	Pedestal damping coefficients, lbs.sec/in.
ω	Angular speed of rotor, radians/sec.
ω_n	Critical rotor speed, radians/sec.

Subscripts and Superscripts

x	in x-direction
y	in y-direction
xx, xy, yx, yy	first index gives force direction, second index gives amplitude direction.
c	cosine component
s	sine component
n	applies to station n
p	pedestal
$(\,)'$	relative between journal and pedestal

INTRODUCTION

A rotor supported in fluid film journal bearings is a complex dynamical syst which exhibits a variety of physical characteristics: critical speeds, insta ility, unbalance vibrations, etc. In designing a rotor-bearing system for a given application it is necessary to have methods available from which these performance characteristics of the system can be predicted and thereby ensur that the design is adequate for the specified operational conditions. It is the purpose of the present report to describe two computer programs by which a particular rotor-bearing system can be investigated. The first program: "Unbalance Response of a Rotor in Fluid Film Bearings" calculates the whirl amplitudes induced by a specified unbalance. The second program: "The Stabi of a Rotor in Fluid Film Bearings", calculates the threshold of instability for the rotor-bearing system.

In the dynamics of a rotor-bearing system the fluid film journal bearings pl a very important role. They are normally the predominant source of damping such that without this source it would be impossible to run the rotor throug any of its critical speeds. Secondly, the bearing film is flexible and ther it may lower the critical speeds drastically. The film flexibility also cau the bearing to act as a vibration isolator, attenuating the dynamical forc transmitted to the pedestals. Finally, if the speed gets sufficiently high the bearing film looses its ability to dampen out any transient motion of th rotor and transfers instead energy from the rotation of the rotor into a wh ing motion of the rotor mass. This is called fractional frequency whirl ("oil whip") and is a self-excited instability of the rotor bearing system. speed at the onset of the instability is called the threshold speed and as rotor speed is increased beyond the threshold speed the whirl amplitude inc rapidly, preventing further operation of the machine. It is, therefore, nec at the design stage to ensure that the selected rotor-bearing system does no experience instability in the operating speed range. Likewise, it is also d sirable to evaluate the magnitude of the rotor amplitude due to a residual u balance such that too large amplitudes will not be encountered in the actual machine. The two computer programs described in the present report provide method for performing these calculations.

The unbalance response program is very general. It calculates the rotor whirl amplitude and the force transmitted to the base due to a given rotor unbalance. The rotor is flexible and may have any arbitrary geometry. Also, there can be splined couplings in the rotor and several bearings. The bearing pedestals can be assigned both flexibility and damping. Since the bearing film forces are not the same in all directions the whirl motion of the rotor is treated as two-dimensional such that it becomes an orbit around the equilibrium position. The orbit is elliptical and its dimensions and orientation vary along the length of the rotor. The computer program calculates the whirl orbits for a number of points along the rotor and gives also the components of the force transmitted to the foundations.

The program for investigating the stability of the rotor-bearing system applies to an arbitrary rotor geometry. There may be several bearings and the stiffness and damping of the bearing pedestals can be included. The program calculates the speed at onset of instability (the threshold speed) and the corresponding whirl frequency.

In both programs, the dynamic properties of a fluid film bearing are expressed in terms of 8 coefficients: 4 spring coefficients and 4 damping coefficients. The coefficients depend on the bearing type, the bearing dimensions, the viscosity of the lubricant, the bearing load and the rotor speed. The values of the coefficients are given in a previous report (Ref. 6) for a wide variety of bearing types, geometries and operating conditions.

The report sets forth the analyses on which the computer programs are based. Detailed instructions are given for preparing the computer input and for interpreting the output.

DISCUSSION

a. General

The computer programs determine the interaction between the bearings and the rotor. The unbalance response program is concerned with the synchronous amplitude of the system under the action of unbalance forces and the stability program is concerned with the free, self-excited motion at the onset of hydrodynamic instability ("oil whip"). Whereas the dynamic properties of the bearings derive from lubrication theory (Ref. 4), the analysis of the rotor itself derives in its principle from the Myklestad-Prohl method (Refs.1, 2, 3). However, in its original form, the Myklestad-Prohl method is set up only for calculating the critical speeds of the rotor and is further limited to plane vibrations. In the present analysis the motion is treated as two-dimensional, damping is included in the bearings in addition to stiffness and the analysis is valid for any speed, not just the critical speed.

In general a rotor's cross-sectional dimensions and its mass distribution varies along the length of the rotor. Thus, for calculation purposes it is convenient to break the rotor up into short sections, each section having a constant cross-section. Furthermore, when there are many sections, the mass of each section can be divided into two parts and lumped at the end points of the section. Concentrated masses like wheels, impellers, etc., can be made to coincide with an end point of a section. In this way the rotor is replaced by an idealized model consisting of a number of mass points connected by weightless, flexible bars. The model can be brought as close to the actual rotor as desired by making the subdivisions small but in practice only a limited number of divisions is needed to obtain a very good accuracy.

Since the bearing film properties to a large extent control the whirl motion and the stability of the rotor, it is necessary to represent the dynamical bearing film forces as accurately as possible. The method of representation is based on the assumption that the whirl amplitude is small compared to the bearing clearance such that the dynamical forces can be replaced by their gradients around the steady state journal center position. In this way the dynamical

forces become proportional to the whirl amplitude and to the corresponding velocity, and the factors of proportionality are called spring and damping coefficients. They differ from conventional mechanical spring-dashpot systems by also containing cross-coupling terms in addition to direct-coupling terms, i.e., the dynamical force in a given direction (say the x-direction) is not only proportional to the amplitude and velocity components in that direction but is also proportional to the amplitude and velocity components in the mutually perpendicular direction (i.e., the y-direction). Hence, in an arbitrary reference coordinate system with x and y-axes the two dynamical force components can be expressed by:

$$F_x = -K_{xx}x - C_{xx}\dot{x} - K_{xy}y - C_{xy}\dot{y}$$
$$F_y = -K_{yx}x - C_{yx}\dot{x} - K_{yy}y - C_{yy}\dot{y}$$

where x and y are the amplitude components, $\dot{x}$ and $\dot{y}$ are the velocity components K_{xx} and K_{yy} are the direct coupling spring coefficients, C_{xx} and C_{yy} are the direct-coupling damping coefficients, K_{xy} and K_{yx} are the cross-coupling spring coefficients, and C_{xy} and C_{yx} are the cross-coupling damping coefficients. These 8 coefficients are functions of the bearing Sommerfeld number defined through the rotor speed, the steady state bearing reactions, the lubricant viscosity and the bearing dimensions (for gas bearings the coefficients are functions of the compressibility number, the bearing eccentricity ratio and the whirl frequency). Thus, the coefficients vary with speed. A method for calculating the coefficients is given in Refs. 4 and 5 and values of the coefficients for several bearing types may be found in Ref. 6.

Frequently the pedestals, on which the bearings are mounted, are as flexible as the bearing film. In such cases, the pedestal stiffness must be included in the calculations. For completeness the analysis allows for both stiffness, damping and inertia in the pedestals. Furthermore, as the rotor bends under the influence of the unbalance forces, the journals become cocked in their bearings. The fluid film resists the tilting and this can be expressed by a set of 8 spring and damping coefficients in analogy to the previously discussed coefficients. The unbalance response analysis includes this effect, both in the bearings and in the pedestals. The resistance to tilt normally affects the rotor motion only at speeds above the second or third critical speed but if the pedestals are made

soft for alignment purposes resonance conditions may exist which can only be explored if the effect of tilt is included. For the stability analysis this effect is in almost all cases very small and it has been ignored.

Occasionally the rotor is not a single member but consists of several rotors connected by splined couplings (e.g., a turbine-generator set connected by a splined coupling). The unbalance response program allows for including splined couplings anywhere in the rotor and assumes that no bending moment is transferred through the coupling. This feature is not included in the stability program.

In the unbalance response program the whirling motion of the rotor is generated by unbalances built into the rotor. In general the unbalance varies in magnitude and circumferential location along the rotor such that under speed the unbalance forces may bend the rotor into complicated shapes (e.g., resembling a "cork-screw") The bend rotor whirls around its steady state position (i.e., the position the rotor would occupy if there were no unbalance forces) with each point of the rotor axis describing an elliptical path. The dimensions and orientation of the ellipse varies along the length of the rotor.

If the rotor runs at high speed and has large disks (e.g., turbine wheels, etc.) mounted on the shaft the gyroscopic moment becomes important, especially if a wheel is overhung at one end of the rotor. The gyroscopic moment is proportional to the mass-moment of inertia of the wheel, the square of the speed and the deflection angle of the rotor. If the rotor motion is considered as a transverse vibration of a beam (i.e., the whirl orbit is a straight line) the gyroscopic moment tends to "soften" the rotor and lower the critical speed. On the other hand, if the bearing spring and damping coefficients are the same in the vertical and the horizontal direction the rotor whirl orbit becomes a circle and the gyroscopic moment stiffens the rotor. Actually, the whirl orbit is elliptical, i.e., somewhere between a straight line and a circle, and the effect of the gyroscopic moment can only be assessed by performing the complete rotor analysis. It is a non-linear effect since it depends on the dimensions of the elliptical whirl orbit. In the present analysis the gyroscopic moment is taken into account in the unbalance response program and is calculated by an iteration procedure.

b. Special Considerations in Performing the Numerical Calculations

The greatest difficulty encountered in performing the numerical calculations is the magnitude of the numbers and the loss of significant figures. These difficulties become pronounced when: a) there is an excessive number of rotor mass stations, b) the rotor is very stiff and, c) the bearings are very stiff. There is no universal remedy for the problem but if trouble arises two possibilities may be tried: a) reduce the number of rotor stations to the essential minimum and, b) apply a scale factor.

Let the scale factor be α. Then:

multiply the speed by α.
multiply (EI) by α^2 (e g., multiply E by α^2)
multiply the bearing spring and damping coefficients by α^2
(i.e., multiply K_{xx}, ωC_{xx}, M_{xx}, ωD_{xx} etc. by α^2)
multiply the pedestal stiffness by α^2 and the pedestal damping coefficients by α.
(i.e., multiply $\varkappa_x$ and $\varkappa_y$ by α^2, δ_x and δ_y by α)
leave the rotor masses, the rotor length, the pedestal masses and the unbalance unchanged.

The numerical results will give the amplitude unchanged whereas the bending moment and the transmitted force must be divided by α^2 to obtain the actual values.

c. Analysis and Dimensionless Equations

Referring to the sign convention given in Fig. 2 and considering first a continuous rotor the three basic equations for determining the rotor motion are:

(1-a) Force balance for a shaft increment, dz: $\frac{dV}{dz} = \rho A \omega^2 (x+a)$

(2-a) Moment balance for a shaft increment, dz: $\frac{dM}{dz} = V + \omega^2 (i_p - i_T) \frac{dx}{dz}$

(3-a) Shaft deflection: $M = EI \frac{d^2x}{dz^2}$

where:
x - amplitude in vertical direction, inch
y - amplitude in horizontal direction, inch

z - coordinate along the rotor length, inch

a - eccentricity between mass center and shaft center, inch

A - cross-sectional area of shaft, in^2

I - cross-section moment of inertia, in^4

E - Youngs modulus, lbs/in^2

ρ - mass density, $lbs.sec^2/in^4$

$(i_P - i_T)$ - mass moment of inertia per unit length, which is effective in gyroscopic moment, $lbs.sec^2$

ω - angular speed, radians/sec

M - bending moment, lbs.in

V - shear force, lbs.

For the stability analysis set $a = 0$ and redefine ω to mean the whirl frequency. These three equations may be combined to give the familiar 4th-order differential equation governing the unbalance vibrations of a rotor:

(4-a) $$\frac{d^2}{dz^2}\left(EI\frac{d^2x}{dz^2}\right) = \rho A\omega^2(x+a) + \omega^2\frac{d}{dz}\left[(i_P - i_T)\frac{dx}{dz}\right]$$

and the same for the y-direction.
(see Ref. 3, page 330)

For a circular whirl orbit:

$$(i_P - i_T) = \rho I$$

For a straight line orbit:

$$(i_P - i_T) = -\rho I$$

For an elliptical whirl orbit, see Eq.(28) and (29) in this report.

At the bearings there is an abrupt change in the shear force and the bending moment due to the bearing reactions. Let the bearing be at $z = z_o$. Then:

(5-a) $$V_{z=z_o^+} - V_{z=z_o^-} = -(K_{xx} + i\omega C_{xx})x - (K_{xy} + i\omega C_{xy})y$$

(6-a) $$M_{z=z_o^+} - M_{z=z_o^-} = +(M_{xx} + i\omega D_{xx})x + (M_{xy} + i\omega D_{xy})y$$

where K_{xx}, C_{xx}, M_{xx}, D_{xx} etc., are the bearing spring and damping coefficients. Actually, the effect of the pedestal should be included in the above equations as shwon in Eq. (12) and (13) in the analysis.

The numerical method uses Eqs. (1-a), (2-a) and (3-a) by rewriting them into finite difference form:

$$\Delta V = \omega^2 (\rho A \Delta z)(x+a)$$

$$\Delta M = V \cdot \Delta z + \omega^2 \left[(i_p - i_T) \Delta z \right] \left(\frac{dx}{dz} \right)$$

$$\Delta \left(\frac{dx}{dz} \right) = \int_z^{z+\Delta z} \frac{M}{EI} \, dz$$

$$\Delta x = \left(\frac{dx}{dz} \right) \Delta z + \int_z^{z+\Delta z} \int_z^{z+\Delta z} \frac{M}{EI} \, dz \, dz$$

Together with Eqs. (5-a) and (6-a) these equations form a set of recurrence relationships which can be solved step by step, starting from one end of the rotor until reaching the other end. The details are given later.

Occasionally it is desired to perform a dimensionless analysis. The two governing quantities are:

(7-a) $$\omega_n^2 = \frac{(EI)_0}{\ell^2 M_T} = \frac{K_r}{M_T}$$

(8-a) $$K_r = \frac{(EI)_0}{\ell^3}$$

where:

- (EI) - reference value of EI, $lbs.in^2$
- ℓ - rotor span between bearings, inch
- M_T - $\int_0^\ell \rho A dz$, total rotor mass, $lbs.sec^2/in$
- K_r - rotor stiffness, lbs/in
- ω_n - equal to or proportional to a critical rotor speed, rad/sec.

For a uniform shaft (EI = constant, A = Constant):

$$\omega_n^2 = \frac{\pi^2 n^4}{4} \frac{EI}{\ell^3 M_T} = \frac{(\frac{1}{4}\pi^2 n^4 EI)}{\ell^3 M_T}$$

where n designates the order of the critical speed. Thus, for the first mode: $n = 1$ i.e.,

$$(EI)_o = \frac{\pi^2 n^4}{4} EI = 2.4674 \cdot EI \quad \text{(Uniform shaft, first mode)}$$

However, it is not necessary that ω_n be a critical speed but Eq. (7-a) must be satisfied.

The dimensionless parameters become:

$$x' = x/a_o$$
$$z' = z/\ell$$
$$(EI)' = EI/(EI)_o$$
$$V' = V/a_o K_r$$
$$M' = M/a_o K_r \ell$$
$$K'_{xx} = K_{xx}/K_r = \left(\frac{W_o}{C_o K_r}\right)\left(\frac{C_o W}{C W_o}\right)\left(\frac{C K_{xx}}{W}\right)$$
$$(\omega C_{xx})' = \omega C_{xx}/K_r = \left(\frac{W_o}{C_o K_r}\right)\left(\frac{C_o W}{C W_o}\right)\left(\frac{C \omega C_{xx}}{W}\right)$$
$$M'_{xx} = M_{xx}/K_r \ell^2 = \left(\frac{W_o}{C_o K_r}\right)\left(\frac{C_o W}{C W_o}\right)\left(\frac{L}{\ell}\right)^2\left(\frac{C M_{xx}}{W L^2}\right)$$
$$(\rho A)' = \ell \rho A/M_T$$
$$(i_p - i_T)' = (i_p - i_T)/M_T \ell$$

where:

- a_o - reference value for the rotor mass eccentricity, inch
- C_o - reference value for the radial bearing clearance, inch
- C - actual radial bearing clearance, inch
- W_o - reference value for the bearing reaction, lbs.
- W - actual bearing reaction, lbs.
- L - bearing length, inch

The dimensionless bearing coefficients are given the form above since the values obtained from lubrication theory are CK_{xx}/W, $C\omega C_{xx}/W$, etc. Normally, a dimensionless analysis is only performed for a simple system where all bearings are identical, i.e. $C = C_o$ and $W = W_o$. In that case the basic dimensionless parameters are:

speed ratio: $(\frac{\omega}{\omega_n})$
dimensionless rotor stiffness: $K'_r = CK_r/W$
dimensionless bearing coefficients: CK_{xx}/W, $C\omega C_{xx}/W$, $(\frac{L}{\ell})^2 (CM_{xx}/WL^2)$ etc.

Thus, to perform a dimensionless calculation for a given value of $K'_{r\ell}$, use as input to the unbalance response computer program:

$$\text{Speed} = (\frac{\omega}{\omega_n})/.10471976$$

$$\text{Mass at station } i = \frac{m_i}{\sum^n m_j} 3.86069 \cdot 10^5$$ (m=station weight, lbs; n=number of stations)

$$(I_p - I_T) \text{ at station } i = \frac{(I_p - I_T)}{M_T \ell^2} 3.86069 \cdot 10^5$$

Cross-sectional moment of inertia for section i-(i+1): $1000 \cdot I/I_o$

Young modulus = 1

Length of section i-(i+1) = ℓ_i/ℓ

Bearing spring coefficient = $\frac{1}{K'_r} (\frac{CK_{xx}}{W})$

Bearing damping coefficient = $\frac{1}{K'_r} (\frac{C\omega C_{xx}}{W})$

Unbalance such that: $\sum_1^n U_x(\text{oz.in}) = 6177.1$ $\sum_1^n U_y\ (\text{oz.in}) = 6177.1$

Then the computer output will give:

amplitude = $\frac{x}{a_o}$ and $\frac{y}{a_o}$

bending moment = $M' = M/a_o K_r \ell = M/\frac{a_o}{C} W \ell K'_r$

transmitted force = (actual force)$/a_o K_r$ = (actual force)$/ \frac{a_o}{C} W K'_r$

COMPUTER PROGRAM: UNBALANCE RESPONSE OF A ROTOR IN FLUID FILM BEARINGS

This section of the report describes the basic analysis and the detailed instructions for using the computer program: PN0011: "Unbalance Response of a Rotor in Fluid Film Journal Bearings" for the IBM 704 digital computer. The program calculates the rotor deflection and bending moment, the pedestal deflection and the transmitted force resulting from a specified rotor unbalance. It differs from conventional programs by taking into account the variation of support flexibility and damping along the whirl path of the rotor.

The supports for the rotor consist of a fluid film bearing on a pedestal, both members possessing flexibility and damping for translatory and rotational motion. The flexibility and damping are linear in displacement and velocity respectively, the proportionality factors denoted as spring and damping coefficients. The fluid film is represented by 4 spring coefficients and 4 damping coefficients for translatory motion and similarly for rotational motion, thus allowing for coupling between the motion in two mutually perpendicular directions. The pedestal has no such coupling and is represented by 2 spring and 2 damping coefficients for both translatory and rotational motion with corresponding pedestal mass and mass moment of inertia. Hence, each point of the rotor will whirl in an elliptic path around its steady state position.

In addition, the program includes the effect of gyroscopic moment and provides for couplings in the rotor.

THEORETICAL ANALYSIS

The analysis is an extension of the Myklestad-Prohl method, see Ref. 1, 2 and 3. The rotor, which is actually a continuous system with an infinite number of degrees of freedom, is replaced by a finite number of lumped masses connected by weightless springs. The computer program calculates the vibrational response of this equivalent system exactly.

Thus the accuracy of the results depends only on how closely the idealized system resembles the actual rotor.

Starting from the left end of the rotor, the program calculates step by step the bending moment, shear force, slope and deflection along the rotor. Neglecting the shear force contribution to the deflection, we get from Fig. 1:

(1) $$M_{n+1} = M'_n + L_n V_n$$

(2) $$\theta_{n+1} = \theta_n + a_n M'_n + b_n V_n$$

(3) $$X_{n+1} = X_n + L_n \theta_n + C_n M'_n + d_n V_n$$

where:

(4) $$a_n = \int_0^{L_n} \frac{d\xi}{EI} = \frac{L_n}{EI}$$ for EI constant in $0 \leq \xi \leq L_n$

(5) $$b_n = \int_0^{L_n} \frac{\xi d\xi}{EI} = \frac{L_n^2}{2EI}$$ " "

(6) $$C_n = L_n a_n - b_n = \frac{L_n^2}{2EI}$$ " "

(7) $$d_n = L_n b_n - \int_0^{L_n} \frac{\xi^2 d\xi}{EI} = \frac{L_n^3}{6EI}$$ " "

The program assumes EI constant between mass points. At the mass points, the forces acting on the rotor are introduced. Four contributions exist: (1) inertia force, (2) unbalance forces, (3) bearing reaction, and (4) gyroscopic moment. In general, not all 4 contributions apply to each mass point.

Inertia force. The rotor performs harmonic vibrations at the same frequency as the rotational speed. Thus the inertia force is:

(8) $$-m \frac{\partial^2 x}{\partial t^2} = m\omega^2 x$$

(9) $$-m \frac{\partial^2 y}{\partial t^2} = m\omega^2 y$$

Unbalance forces. To allow for change in circumferential position of the unbalance along the rotor, the unbalance is given two components U_x and U_y. This gives rise to an x and y component of the unbalance force:

(10) $$(V_{xn} - V_{x,n+1})_{unb.} = \omega^2 U_x \cos\omega t - \omega^2 U_y \sin\omega t$$

(11) $$(V_{y,n} - V_{y,n+1})_{unb.} = \omega^2 U_y \cos\omega t + \omega^2 U_x \sin\omega t$$

Bearing reaction. The bearing supports have flexibility and damping for both translatory and rotational motion of the rotor. Since the equations for the two types of motion are analogous, only the equations for translatory motion will be derived.

The bearing support is shown in Fig. 3. It consists of a pedestal with mass (M_{ox}, M_{oy}), supported by springs ($\aleph_x, \aleph_y$) and dashpots (σ_x, σ_y). There is no coupling between the x and y direction, i.e. no transfer impedance, nor between the translatory and rotational motion. The pedestal supports the bearing fluid film which is represented by 4 springs and 4 damping coefficients. If the relative motion between the journal center and the bearing housing is denoted (x', y'), then the bearing reaction becomes:

(12) $$\begin{aligned}(V_{xn} - V_{x,n-1})_{bearing} &= -K_{xx}x' - C_{xx}\dot{x}' - K_{xy}y' - C_{xy}\dot{y}' \\ (V_{yn} - V_{y,n-1})_{bearing} &= -K_{yx}x' - C_{yx}\dot{x}' - K_{yy}y' - C_{yy}\dot{y}'\end{aligned}$$

Setting:

$$x' = x'_c \cos\omega t + x'_s \sin\omega t$$
$$y' = y'_c \cos\omega t + y'_s \sin\omega t.$$

we get from Newton's second law for the pedestal mass:

$$(K_{xx}+\gamma_x-\omega^2 M_{ox})X'_c+\omega(C_{xx}+\sigma_x)X'_s+K_{xy}y'_c+\omega C_{xy}y'_s=(\gamma_x-\omega^2 M_{ox})X_c+\omega\sigma_x X_s$$

(13)

$$-\omega(C_{xx}+\sigma_x)X'_c+(K_{xx}+\gamma_x-\omega^2 M_{ox})X'_s-\omega C_{xy}y'_c+K_{xy}y'_s=-\omega\sigma_x X_c+(\gamma_x-\omega^2 M_{ox})X_s$$

$$K_{yx}X'_c+\omega C_{yx}X'_s+(K_{yy}+\gamma_y-\omega^2 M_{oy})y'_c+\omega(C_{yy}+\sigma_y)y'_s=(\gamma_y-\omega^2 M_{oy})y_c+\omega\sigma_y y_s$$

$$-\omega C_{yx}X'_c+K_{yx}X'_s-\omega(C_{yy}+\sigma_y)y'_c+(K_{yy}+\gamma_y-\omega^2 M_{oy})y'_s=-\omega\sigma_y y_c+(\gamma_y-\omega^2 M_{oy})y_s$$

Solving the equations we obtain:

$$(V_{xn}-V_{x,n-1})_{bearing}=(-\Delta V_{ax}X_c-\Delta V_{bx}X_s-\Delta V_{cx}y_c-\Delta V_{dx}y_s)\cos\omega t$$

(14)

$$+(\Delta V_{bx}X_c-\Delta V_{ax}X_s+\Delta V_{dx}y_c-\Delta V_{cx}y_s)\sin\omega t$$

$$(V_{yn}-V_{y,n-1})_{bearing}=(-\Delta V_{cy}X_c-\Delta V_{dy}X_s-\Delta V_{ay}y_c-\Delta V_{by}y_s)\cos\omega t$$

$$+(\Delta V_{dy}X_c-\Delta V_{cy}X_s+\Delta V_{by}y_c-\Delta V_{ay}y_s)\sin\omega t$$

where:

$$\Delta V_{ax}=K_{xx}f+\omega C_{xx}g+K_{xy}q+\omega C_{xy}r$$

$$\Delta V_{bx}=-K_{xx}g+\omega C_{xx}f-K_{xy}r+\omega C_{xy}q$$

$$\Delta V_{cx}=K_{xx}h+\omega C_{xx}i+K_{xy}s+\omega C_{xy}t$$

(15)

$$\Delta V_{dx}=-K_{xx}i+\omega C_{xx}h-K_{xy}t+\omega C_{xy}s$$

$$\Delta V_{ay}=K_{yx}h+\omega C_{yx}i+K_{yy}s+\omega C_{yy}t$$

$$\Delta V_{by}=-K_{yx}i+\omega C_{yx}h-K_{yy}t+\omega C_{yy}s$$

$$\Delta V_{cy}=K_{yx}f+\omega C_{yx}g+K_{yy}q+\omega C_{yy}r$$

$$\Delta V_{dy}=-K_{yx}g+\omega C_{yx}f-K_{yy}r+\omega C_{yy}q$$

and:

$$f = \frac{GE + FD}{F^2 + G^2} \qquad g = \frac{GD - FE}{F^2 + G^2}$$

$$h = \frac{GJ + FH}{F^2 + G^2} \qquad i = \frac{GH - FJ}{F^2 + G^2}$$

$$F = A - K_{xy} Q + \omega C_{xy} R \qquad G = B - K_{xy} R - \omega C_{xy} Q$$

$$H = -K_{xy} S + \omega C_{xy} T \qquad J = -K_{xy} T - \omega C_{xy} S$$

$$Q = \frac{K_{yx} a + \omega C_{yx} b}{a^2 + b^2} \qquad R = \frac{\omega C_{yx} a - K_{yx} b}{a^2 + b^2}$$

$$S = \frac{ad + be}{a^2 + b^2} \qquad T = \frac{ae - bd}{a^2 + b^2}$$

$$A = K_{xx} + \gamma_x - \omega^2 M_{ox} \qquad B = \omega (C_{xx} + \sigma_x)$$

$$D = \gamma_x - \omega^2 M_{ox} \qquad E = \omega \sigma_x$$

$$a = K_{yy} + \gamma_y - \omega^2 M_{oy} \qquad b = \omega (C_{yy} + \sigma_y)$$

$$d = \gamma_y - \omega^2 M_{oy} \qquad e = \omega \sigma_y$$

$$q = -Qf - Rg \qquad r = -Qg + Rf$$

$$s = S - Qh - Ri \qquad t = -T - Qi + Rh$$

The equations for rotational motion are analogous to eq. (14)except for a sign reversal (sign convention, see Fig. 2):

$$(16) \quad \begin{aligned} (M_{xn}' - M_{xn})_{bearing} &= (\Delta M_{ax}\theta_c + \Delta M_{bx}\theta_s + \Delta M_{cx}\varphi_c + \Delta M_{dx}\varphi_s) \cos\omega t \\ &\quad + (-\Delta M_{bx}\theta_c + \Delta M_{ax}\theta_s - \Delta M_{dx}\varphi_c + \Delta M_{cx}\varphi_s) \sin\omega t \\ (M_{yn}' - M_{yn})_{bearing} &= (\Delta M_{cy}\theta_c + \Delta M_{dy}\theta_s + \Delta M_{ay}\varphi_c + \Delta M_{by}\varphi_s) \cos\omega t \\ &\quad + (-\Delta M_{dy}\theta_c + \Delta M_{cy}\theta_s - \Delta M_{by}\varphi_c + \Delta M_{ay}\varphi_s) \sin\omega t \end{aligned}$$

where the coefficients $\Delta M_{ay}, \Delta M_{bx}$ etc. are computed from eq. (15) as $\Delta M_{ax} = \Delta V_{ax}$, $\Delta M_{bx} = \Delta V_{bx}$ etc. by replacing the translatory spring and damping coefficients by the corresponding rotational coefficients.

Since the fluid film coefficients are functions of speed, directly through the Sommerfeld number and indirectly through the decrease of eccentricity ratio with increasing speed, the computer program provides for expressing the coefficients as a function of speed, e.g.

$$K_{xx} = K_{xx,0} + K_{xx,1} \cdot \omega + K_{xx,2} \cdot \omega^2 \tag{18}$$

and similarly for the other coefficients. ω is the rotor speed in radians/sec.

Gyroscopic Moment. The gyroscopic moment derives from the change of the angular momentum vector of the rotating rotor mass as it whirls in an elliptical path around the steady state position of the rotor. For two special cases the gyroscopic moment is known:

(19)

circular whirl path: $M_{Gyr.} = (I_P - I_T)\omega^2\theta$

straight line (transverse vibrations): $M_{Gyr.} = -I_T\omega^2\theta$

where θ is the slope of the rotor deflection and I_P and I_T are the polar and transverse mass momentsof inertia. For an elliptical path the gyroscopic moment is no longer linear with respect to the slope of the rotor, indicating that an elliptical path is actually not possible. However, in general the effect of the gyroscopic moment is not too big and for the present analysis an elliptical path will be assumed.

The coordinate system is shown in Fig. 4, where O is the steady state shaft center position and O' is the whirling shaft center. The moving coordinate system (ξ, η, ζ) is defined by its unit vectors:

$$\bar{e}_\xi = \left(\frac{\theta/\sqrt{\theta^2+\varphi^2}}{\sqrt{1+\theta^2+\varphi^2}} , \frac{\varphi/\sqrt{\theta^2+\varphi^2}}{\sqrt{1+\theta^2+\varphi^2}} , \frac{-\sqrt{\theta^2+\varphi^2}}{\sqrt{1+\theta^2+\varphi^2}} \right) \simeq \left(\frac{\theta}{\sqrt{\theta^2+\varphi^2}} , \frac{\varphi}{\sqrt{\theta^2+\varphi^2}} , \sqrt{\theta^2+\varphi^2} \right)$$

$$\text{(20)} \qquad \bar{e}_\eta = \left(\frac{-\varphi}{\sqrt{\theta^2+\varphi^2}} , \frac{\theta}{\sqrt{\theta^2+\varphi^2}} , 0 \right)$$

$$\bar{e}_\zeta = \left(\frac{\theta}{\sqrt{1+\theta^2+\varphi^2}} , \frac{\varphi}{\sqrt{1+\theta^2+\varphi^2}} , \frac{1}{\sqrt{1+\theta^2+\varphi^2}} \right) \simeq \left(\theta , \varphi , 1 \right)$$

The angular velocity vector becomes:

$$\text{(21)} \qquad \bar{\omega} = \left(\omega_\xi , \omega_\eta , \omega_\zeta \right) = \left(\dot{e}_\eta e_\zeta , \dot{e}_\zeta e_\xi , \dot{e}_\xi e_\eta \right) = \left(\frac{\dot{\theta}\varphi - \theta\dot{\varphi}}{\sqrt{\theta^2+\varphi^2}} , \frac{\theta\dot{\theta}+\varphi\dot{\varphi}}{\sqrt{\theta^2+\varphi^2}} , -\frac{(\dot{\theta}\varphi-\theta\dot{\varphi})}{\theta^2+\varphi^2} \right)$$

The moment needed to sustain the motion is given by Eulers equations:

$$M_\xi = I_T \dot{\omega}_\xi + (I_p - I_T) \omega_\zeta \omega_\eta$$

$$\text{(22)} \qquad M_\eta = I_T \dot{\omega}_\eta + (I_p - I_T) \omega_\zeta \omega_\xi$$

$$M_\zeta = I_p \dot{\omega}_\zeta$$

where I denotes mass moment of inertia and $I_\xi = I_T$, $I_\eta = I_T$ and $I_\zeta = I_p$.

Let us first assume that (x, y) corresponds to the directions of the major and minor axis in the elliptical variation of the rotor slope. Then:

$$\theta_1 = E \cos(\omega t + \alpha)$$

$$\text{(23)}$$

$$\varphi_1 = G \sin(\omega t + \alpha)$$

Combining eq. (20), (21) and (22):

$$-M_x = -I_T \omega^2 \varphi_1 + I_p \omega^2 EG \left[2EG \frac{\varphi_1}{(\theta_1^2+\varphi_1^2)} + \frac{\frac{1}{\omega}\dot{\theta}_1}{\theta_1^2+\varphi_1^2} \right]$$

$$\text{(24)}$$

$$M_y = -I_T \omega^2 \theta_1 + I_p \omega^2 EG \left[2EG \frac{\theta_1}{(\theta_1^2+\varphi_1^2)^2} - \frac{\frac{1}{\omega}\dot{\varphi}_1^2}{\theta_1^2+\varphi_1^2} \right]$$

which clearly shows that the gyroscopic moment is not linear with respect to the rotor slope. However, only the first harmonic can do

work on the rotor. Hence a Fourier analysis will be performed. The following integrals apply:

$$\int_0^{2\pi} \frac{\sin x \cos x \, dx}{E^2\cos^2 x + G^2 \sin^2 x} = 0$$

$$\int_0^{2\pi} \frac{\sin x \cos x \, dx}{(E^2\cos^2 x + G^2 \sin^2 x)^2} = 0$$

$$\int_0^{2\pi} \frac{\sin^2 x \, dx}{E^2\cos^2 x + G^2 \sin^2 x} = \frac{2\pi}{G(E+G)}$$

$$\int_0^{2\pi} \frac{\sin^2 x \, dx}{(E^2\cos^2 x + G^2 \sin^2 x)^2} = \frac{\pi}{EG^3}$$

$$\int_0^{2\pi} \frac{dx}{E^2\cos^2 x + G^2 \sin^2 x} = \frac{2\pi}{EG}$$

$$\int_0^{2\pi} \frac{dx}{(E^2\cos^2 x + G^2 \sin^2 x)^2} = \frac{\pi(E^2+G^2)}{E^3G^3}$$

Then the first harmonic becomes:

(24)
$$-M_x = \left(\frac{2E}{E+G} I_P - I_T\right) \omega^2 \varphi_1$$
$$M_y = \left(\frac{2G}{E+G} I_P - I_T\right) \omega^2 \theta_1$$

In the limit, eqs. (24) agree with eqs. (19).
Eqs. (24) must be transformed back to the actual (θ,φ)-coordinate system. Setting

(25)
$$\theta = \theta_c \cos \omega t + \theta_s \sin \omega t$$
$$\varphi = \varphi_c \cos \omega t + \varphi_s \sin \omega t$$

describing an elliptical variation of slope, we get:

$$\left.\begin{matrix} E \\ G \end{matrix}\right\} = \sqrt{\frac{1}{2}\left(\theta_c^2+\theta_s^2+\varphi_c^2+\varphi_s^2\right) \pm \sqrt{\frac{1}{4}\left(\theta_c^2+\theta_s^2+\varphi_c^2+\varphi_s^2\right)^2-\left(\theta_c\varphi_s-\theta_s\varphi_c\right)^2}}$$

(26)

$$\cos 2\beta = \frac{\theta_c^2+\theta_s^2-\varphi_c^2-\varphi_s^2}{\sqrt{\left(\theta_c^2+\theta_s^2-\varphi_c^2-\varphi_s^2\right)^2+4\left(\theta_c\varphi_c+\theta_s\varphi_s\right)^2}}$$

$$\sin 2\beta = \frac{2\left(\theta_c\varphi_c+\theta_s\varphi_s\right)}{\sqrt{\left(\theta_c^2+\theta_s^2-\varphi_c^2-\varphi_s^2\right)^2+4\left(\theta_c\varphi_c+\theta_s\varphi_s\right)^2}}$$

where β is the angle from the position X-axis to the major axis E, position in the same direction as ω. Then:

(27)

$$\theta_1 = \theta\cos\beta + \varphi\sin\beta$$

$$\varphi_1 = -\theta\sin\beta + \varphi\cos\beta$$

Substituting eq. (26)-(27) into eqs. (24) gives:

(28) $$M_y = \left(M'_{xn} - M_{xn}\right)_{Gyro} = \omega^2\left[2\Delta M_{Gx} I_p - \theta_c I_T\right]\cos\omega t + \omega^2\left[2\Delta M_{Gy} I_p - \theta_s I_T\right]\sin\omega t$$

(29) $$-M_x = \left(M'_{yn} - M_{yn}\right)_{Gyro} = \omega^2\left[-2\Delta M_{Gy} I_p - \varphi_c I_T\right]\cos\omega t + \omega^2\left[2\Delta M_{Gx} I_p - \varphi_s I_T\right]\sin\omega t$$

where

(30) $$\Delta M_{Gx} = \frac{\left(\theta_c+\varphi_s\right)\left(\theta_c\varphi_s-\theta_s\varphi_c\right)}{\left(\theta_c+\varphi_s\right)^2+\left(\theta_s-\varphi_c\right)^2}$$

(31) $$\Delta M_{Gy} = \frac{\left(\theta_s-\varphi_c\right)\left(\theta_c\varphi_s-\theta_s\varphi_c\right)}{\left(\theta_c+\varphi_s\right)^2+\left(\theta_s-\varphi_c\right)^2}$$

Since eq. (28) and eq. (29) are not linear, an iterative method is used. For each rotor speed, the program performs a number of iterations. The first iteration is done without gyroscopic moment. After the first iteration, the gyroscopic moment is calculated from eq. (28)-(29) and these values are used in the second iteration and so on. The calculation has converged when the relative change in rotor amplitude and slope between two iterations is smaller than a specified limit.

EQUATIONS FOR ROTOR CALCULATION

The bending moment, the shear force, the slope and the deflection are expressed by:

$$M_x = M_{xc} \cos \omega t + M_{xs} \sin \omega t$$

$$V_x = V_{xc} \cos \omega t + V_{xs} \sin \omega t$$

$$\theta = \theta_c \cos \omega t + \theta_s \sin \omega t$$

$$x = x_c \cos \omega t + x_s \sin \omega t$$

and similarly for the y-direction. Then eq. (1), (2), (3), (8), (9), (10), (11), (14), (16), (17), and (29) may be combined to give the equations used in the rotor calculation (see Fig. 2):

$$M'_{xcn} = M_{xcn} + \Delta M_{axn}\theta_{cn} + \Delta M_{bxn}\theta_{sn} + \Delta M_{cxn}\varphi_{cn} + \Delta M_{dxn}\varphi_{sn} + (M'_{xcn} - M_{xcn})_{gyro}$$

$$M'_{xsn} = M_{xsn} - \Delta M_{bxn}\theta_{cn} + \Delta M_{axn}\theta_{sn} - \Delta M_{dxn}\varphi_{cn} + \Delta M_{cxn}\varphi_{sn} + (M'_{xsn} - M_{xsn})_{gyro}$$

$$M'_{ycn} = M_{ycn} + \Delta M_{cyn}\theta_{cn} + \Delta M_{dyn}\theta_{sn} + \Delta M_{ayn}\varphi_{cn} + \Delta M_{byn}\varphi_{sn} + (M'_{ycn} - M_{ysn})_{gyro}$$

$$M'_{ysn} = M_{ysn} - \Delta M_{dyn}\theta_{cn} + \Delta M_{cyn}\theta_{sn} - \Delta M_{byn}\varphi_{cn} + \Delta M_{ayn}\varphi_{sn} + (M'_{ysn} - M_{ysn})_{gyro}$$

$$V_{xcn} = V_{xc,n-1} + [m_n\omega^2 - \Delta V_{axn}]x_{cn} - \Delta V_{bxn}x_{sn} - \Delta V_{cxn}y_{cn} - \Delta V_{dxn}y_{sn} + \omega^2 U_{xn}$$

$$V_{xsn} = V_{xs,n-1} + \Delta V_{bxn}x_{cn} + [m_n\omega^2 - \Delta V_{axn}]x_{sn} + \Delta V_{dxn}y_{cn} - \Delta V_{cxn}y_{sn} - \omega^2 U_{yn} \tag{32}$$

$$V_{ycn} = V_{yc,n-1} - \Delta V_{cyn}x_{cn} - \Delta V_{dyn}x_{sn} + [m_n\omega^2 - \Delta V_{ayn}]y_{cn} - \Delta V_{byn}y_{sn} + \omega^2 U_{yn}$$

$$V_{ysn} = V_{ys,n-1} + \Delta V_{dyn}x_{cn} - \Delta V_{cyn}x_{sn} + \Delta V_{byn}y_{cn} + [m_n\omega^2 - \Delta V_{ayn}]y_{sn} + \omega^2 U_{xn}$$

$$M_{xc,n+1} = M'_{xcn} + L_n V_{xcn}$$

$$M_{xs,n+1} = M'_{xsn} + L_n V_{xsn}$$

$$M_{yc,n+1} = M'_{ycn} + L_n V_{ycn}$$

$$M_{ys,n+1} = M'_{ysn} + L_n V_{ysn}$$

$$\theta_{c,n+1} = \theta_{cn} + a_n M'_{xcn} + b_n V_{xcn}$$

$$\theta_{s,n+1} = \theta_{sn} + a_n M'_{xsn} + b_n V_{xsn}$$

$$\varphi_{c,n+1} = \varphi_{cn} + a_n M'_{ycn} + b_n V_{ycn}$$

$$\varphi_{s,n+1} = \varphi_{sn} + a_n M'_{ysn} + b_n V_{ysn}$$

$$X_{c,n+1} = X_{cn} + L_n \theta_{cn} + b_n M'_{xcn} + d_n V_{xcn}$$

$$X_{s,n+1} = X_{sn} + L_n \theta_{sn} + b_n M'_{xsn} + d_n V_{xsn}$$

$$y_{c,n+1} = y_{cn} + L_n \varphi_{cn} + b_n M'_{ycn} + d_n V_{ycn}$$

$$y_{s,n+1} = y_{sn} + L_n \varphi_{sn} + b_n M'_{ysn} + d_n V_{ysn}$$

In the above equations a_n, b_n, d_n are given by eq. (4), (5) and (7), $\Delta M_{xam}, \Delta M_{xbm}$ ---------- ΔM_{dyn} and $\Delta V_{xam}, \Delta V_{xbm}$ ------- ΔV_{dyn} by eqs. (15) and $(M'_{xcn} - M_{xcn})_{Gyro}$ ---------- $(M'_{ysn} - M_{ysn})_{Gyro}$ by eq. (28)-(29).

<u>Boundary Conditions</u>. The rotor is assumed to have free ends. No loss in generality occurs by this condition since it may be changed by letting the end points have bearing support. A proper choice of support coefficients will then allow for any type of end conditions.

For a rotor with free ends the bending moment and the shear force are zero at the end:

(33) $M_{xc1} = M_{xs1} = M_{yc1} = M_{ys1} = V_{xc1} = V_{xs1} = V_{yc1} = V_{ys1} = 0$

(34) $M'_{xcr} = M'_{xsr} = M'_{ycr} = M'_{ysr} = V_{xcr} = V_{xsr} = V_{ycr} = V_{ysr} = 0$

Starting from the left end of the rotor (see Fig. 2), eq. (33) is used. However, the slope and the deflection are unknown. Using the superposition principle, each unknown is applied separately. A summation gives the combined effect. Ten calculations are performed, using eqs. (32).

1. $\theta_{c1} = 1$ $\qquad \theta_{s1} = \varphi_{c1} = \varphi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = U_{xn} = U_{yn} = 0$
2. $\theta_{s1} = 1$ $\qquad \theta_{c1} = \varphi_{c1} = \varphi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = U_{xn} = U_{yn} = 0$
3. $\varphi_{c1} = 1$ $\qquad \theta_{c1} = \theta_{s1} = \varphi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = U_{xn} = U_{yn} = 0$
4. $\varphi_{s1} = 1$ $\qquad \theta_{c1} = \theta_{s1} = \varphi_{c1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = U_{xn} = U_{yn} = 0$
5. $\chi_{c1} = 1$ $\qquad \theta_{c1} = \theta_{s1} = \varphi_{c1} = \varphi_{s1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = U_{xn} = U_{yn} = 0$
6. $\chi_{s1} = 1$ $\qquad \theta_{c1} = \theta_{s1} = \varphi_{c1} = \varphi_{s1} = \chi_{c1} = \psi_{c1} = \psi_{s1} = U_{xn} = U_{yn} = 0$
7. $\psi_{c1} = 1$ $\qquad \theta_{c1} = \theta_{s1} = \varphi_{c1} = \varphi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{s1} = U_{xn} = U_{yn} = 0$
8. $\psi_{s1} = 1$ $\qquad \theta_{c1} = \theta_{s1} = \varphi_{c1} = \varphi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = U_{xn} = U_{yn} = 0$
9. $U_{xn} = U_{xn} \quad U_{yn} = U_{yn}$ $\qquad \theta_{c1} = \theta_{s1} = \varphi_{c1} = \varphi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = 0$
10. Gyroscopic moment applied $\qquad \theta_{c1} = \theta_{s1} = \varphi_{c1} = \varphi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = U_{xn} = U_{yn} = 0$

For each calculation eqs. (32) are used to calculate the bending moment, the shear force, the slope and the deflection along the rotor. At the right rotor end, station r, eq. (34) must be satisfied, i.e.

$$
\begin{Bmatrix}
M'_{xcr,1} & M'_{xcr,2} & \cdots & M'_{xcr,8} \\
M'_{xsr,1} & M'_{xsr,2} & \cdots & M'_{xsr,8} \\
M'_{ycr,1} & M'_{ycr,2} & \cdots & M'_{ycr,8} \\
M'_{ysr,1} & M'_{ysr,2} & \cdots & M'_{ysr,8} \\
V_{xcr,1} & V_{xcr,2} & \cdots & V_{xcr,8} \\
V_{xsr,1} & V_{xsr,2} & \cdots & V_{xsr,8} \\
V_{ycr,1} & V_{ycr,2} & \cdots & V_{ycr,8} \\
V_{ysr,1} & V_{ysr,2} & \cdots & V_{ysr,8}
\end{Bmatrix}
\begin{Bmatrix}
\theta_{c1} \\ \theta_{s1} \\ \varphi_{c1} \\ \varphi_{s1} \\ \chi_{c1} \\ \chi_{s1} \\ \psi_{c1} \\ \psi_{s1}
\end{Bmatrix}
=
\begin{Bmatrix}
-M'_{xcr,9} - M'_{xcr,10} \\
-M'_{xsr,9} - M'_{xsr,10} \\
-M'_{ycr,9} - M'_{ycr,10} \\
-M'_{ysr,9} - M'_{ysr,10} \\
-V_{xcr,9} - V_{ycr,10} \\
-V_{xsr,9} - V_{xsr,10} \\
-V_{ycr,9} - V_{ycr,10} \\
-V_{ysr,9} - V_{ysr,10}
\end{Bmatrix}
\tag{35}
$$

Eqs. (35) are then solved for $\theta_{c1}, \theta_{s1} \cdots \psi_{s1}$, and the actual values of bending moment, shear force etc, along the rotor can be determined. At a given rotor speed, eqs. (35) are first solved without gyroscopic

moment, i.e. $M'_{xcr,10} = \cdots\cdots = V_{ysr,1} \neq 0$. Then the gyroscopic moment is applied according to eq. (28)-(29) and new values are found for $\theta_{c1}, \theta_{s1}, \cdots\cdots \psi_{s1}$ from eqs. (35). This process is repeated until at the k'th iteration:

$$(36) \qquad \frac{|\theta_{c1}^{(k)}-\theta_{c1}^{(k-1)}|+|\theta_{s1}^{(k)}-\theta_{s1}^{(k-1)}|+|\varphi_{c1}^{(k)}-\varphi_{c1}^{(k-1)}|+\cdots\cdots+|\psi_{s1}^{(k)}-\psi_{s1}^{(k-1)}|}{|\theta_{c1}^{(k)}|+|\theta_{s1}^{(k)}|+|\varphi_{c1}^{(k)}|+\cdots\cdots|\psi_{s1}^{(k)}|} \leq \varepsilon_{Gyro}$$

where ε_{Gyro} is the convergence limit specified by the computer input. If the calculation does not converge within a specified number of iterations, the program goes on to a new rotor speed.

In the computer output, the rotor deflection is given by the dimensions of the elliptical whirl path. We have:

$$(37) \qquad \begin{aligned} x &= x_c \cos\omega t + x_s \sin\omega t \\ y &= y_c \cos\omega t + y_s \sin\omega t \end{aligned}$$

As shown in Fig. 5, the (x,y)-coordinate system is rotated an angle β in the same direction as ω to become (x_1, y_1). Then

$$(38) \qquad \begin{aligned} x_1 &= a \cos(\omega t + \alpha) \\ y_1 &= b \sin(\omega t + \alpha) \end{aligned}$$

where a and b are the major and minor axis respectively of the ellipse. From Fig. 5:

$$\begin{aligned} x_1 &= x\cos\beta + y\sin\beta \\ y_1 &= -x\sin\beta + y\cos\beta \end{aligned}$$

Then:

$$(39) \qquad \left.\begin{matrix} a \\ b \end{matrix}\right\} = \sqrt{\frac{1}{2}\left[(x_c^2+x_s^2+y_c^2+y_s^2) \pm \sqrt{(x_c^2+x_s^2-y_c^2-y_s^2)^2+4(x_c y_c + x_s y_s)^2}\right]}$$

Here it is necessary to allow b to become negative. The reason is that the transformation from the x-y-coordinates to the ellipse must be able to discern between forward and backward whirl (i.e. the shaft center may travel in the same direction or in the opposite direction of the direction of rotation depending on the values of x_c, x_s, y_c and y_s). Let the angle between the x-axis and the instantaneous radius vector be γ :

$$\gamma = \tan^{-1}\left(\frac{y}{x}\right)$$

Then:

$$\dot{\gamma} = \frac{x\dot{y} - \dot{x}y}{x^2+y^2} = \frac{\omega[x_c y_s - x_s y_c]}{x^2+y^2}$$

i.e.

$$(x_c y_s - x_s y_c) > 0 \quad : \text{forward whirl}$$

$$(x_c y_s - x_s y_c) < 0 \quad : \text{backward whirl}$$

$$(x_c y_s - x_s y_c) = 0 \quad : \text{straight line orbit } (b=0)$$

Therefore:

(39a)
$$b = \frac{(x_c y_s - x_s y_c)}{|x_c y_s - x_s y_c|} \sqrt{\frac{1}{2}\left[(x_c^2+x_s^2+y_c^2+y_s^2) - \sqrt{(x_c^2+x_s^2-y_c^2-y_s^2)^2 + 4(x_c y_c + x_s y_s)^2}\,\right]}$$

To find α and β expand Eq.(38)

(a) $\quad a\cos\alpha = x_c\cos\beta + y_c\sin\beta$

(b) $\quad -a\sin\alpha = x_s\cos\beta + y_s\sin\beta$

(c) $\quad b\sin\alpha = -x_c\sin\beta + y_c\cos\beta$

(d) $\quad b\cos\alpha = -x_s\sin\beta + y_s\cos\beta$

Then:

$(a)^2+(b)^2+(c)^2+(d)^2 : \quad a^2+b^2 = x_c^2+x_s^2+y_c^2+y_s^2$

$(a)^2+(b)^2-(c)^2-(d)^2 : \quad a^2-b^2 = (x_c^2+x_s^2-y_c^2-y_s^2)\cos 2\beta + 2(x_c y_c + x_s y_s)\sin 2\beta$

i.e. $\quad \cos 2\beta = \dfrac{x_c^2+x_s^2-y_c^2-y_s^2}{a^2-b^2} \qquad \sin 2\beta = \dfrac{2(x_c y_c + x_s y_s)}{a^2-b^2}$

Next:

$-(a)\cdot(b) - (c)\cdot(d) : \quad \frac{1}{2}(a^2-b^2)\sin 2\alpha = -(x_c x_s + y_c y_s)$

$(a)^2-(b)^2+(c)^2-(d)^2 : \quad (a^2-b^2)\cos 2\alpha = x_c^2 - x_s^2 + y_c^2 - y_s^2$

i.e. $\quad \cos 2\alpha = \dfrac{x_c^2-x_s^2+y_c^2-y_s^2}{a^2-b^2} \qquad \sin 2\alpha = \dfrac{-2(x_c x_s + y_c y_s)}{a^2-b^2}$

Thus in total:

(40) $\tan 2\beta = \dfrac{2(X_c Y_c + X_s Y_s)}{X_c^2 + X_s^2 - Y_c^2 - Y_s^2}$ $\qquad \cos 2\beta = \dfrac{X_s^2 - Y_c^2 - Y_s^2}{b^2}$

(41) $\tan 2\alpha = \dfrac{-2(X_c X_s + Y_c Y_s)}{X_c^2 - X_s^2 + Y_c^2 - Y_s^2}$ $\qquad \cos 2\alpha = \dfrac{X_c^2 - X_s^2 + Y_c^2 - Y_s^2}{a^2 - b^2}$

Thus β is the angle from the positive X-axis to the major axis of the ellipse (positive with ω) and α is the phase angle for the radius vector, measured positive from the major axis in the direction of ω. The computer output gives a, b, β and α for both the deflection and the bending moment.

Coupling Stations. The programs allow for couplings in the rotor. At these stations, the bending moment vanishes, i.e. $M_n' = 0$ (the coupling point is taken just to the right of the mass station). When the program encounters a coupling station, say station i, the following equations are set up:

$$(42)\quad \begin{bmatrix} M_{xci,1} & M_{xci,2} & \cdots & M_{xci,4} \\ M_{xsi,1} & M_{xsi,2} & \cdots & M_{xsi,4} \\ M_{yci,1} & M_{yci,2} & \cdots & M_{yci,4} \\ M_{ysi,1} & M_{ysi,2} & \cdots & M_{ysi,4} \end{bmatrix} \begin{bmatrix} \theta_{c1} \\ \theta_{s1} \\ \varphi_{c1} \\ \varphi_{s1} \end{bmatrix} = - \begin{bmatrix} M'_{xci,5} & \cdots & M'_{xci,8} \\ M'_{xsi,5} & \cdots & M'_{xsi,8} \\ M'_{yci,5} & \cdots & M'_{yci,8} \\ M'_{ysi,5} & \cdots & M'_{ysi,8} \end{bmatrix} \begin{bmatrix} X_{c1} \\ X_{s1} \\ Y_{c1} \\ Y_{s1} \end{bmatrix} - \begin{bmatrix} M'_{xci,9} + M'_{xci,10} \\ M'_{xsi,9} + M'_{xsi,10} \\ M'_{yci,9} + M'_{yci,10} \\ M'_{ysi,9} + M'_{ysi,10} \end{bmatrix}$$

or upon solving

$$(43)\qquad \theta_i = a_{ij} X_j + b_i \qquad (i,j = 1,2,3,4)$$

where $\theta_1 = \theta_{c1}, \theta_2 = \theta_{c2}$ etc. and $X_1 = X_{c1}, X_2 = X_{s1}$ etc. Then the bending moment, shear force, slope and deflection before the coupling station become functions of X_{c1}, X_{s1}, Y_{c1} and Y_{s1} only. As an example, let the shear force at a station be:

$$V_{xcn} = V_1\theta_{c1} + V_2\theta_{s1} + V_3\varphi_{c1} + V_4\varphi_{s1} + V_5 X_{c1} + V_6 X_{s1} + V_7 Y_{c1} + V_8 Y_{s1} + V_9 + V_{10}$$

Introducing eq. (43) gives:

$$V_{xcn} = \left[V_5 + a_{11}V_1 + a_{21}V_2 + a_{31}V_3 + a_{41}V_4\right]x_{c1} + \left[V_6 + a_{12}V_1 + a_{22}V_2 + a_{32}V_3 + a_{42}V_4\right]x_{s1}$$

$$\text{(44)} \quad + \left[V_7 + a_{13}V_1 + a_{23}V_2 + a_{33}V_3 + a_{43}V_4\right]y_{c1} + \left[V_8 + a_{14}V_1 + a_{24}V_2 + a_{34}V_3 + a_{44}V_4\right]y_{s1}$$

$$+ \left[V_9 + V_{10} + b_1V_1 + b_2V_2 + b_3V_3 + b_4V_4\right]$$

and similarly for $V_{xsn}, V_{ycn}, V_{ysn}, M_{xcn}, ----- y_{sn}$. Instead of $\theta_{c1}, \theta_{s1}, \varphi_{c1}$ and φ_{s1} we have as new variables the slopes just to the right of the coupling station m, i.e. $\theta_{cm}, \theta_{sm}, \varphi_{cm}, \varphi_{sm}$. Then the calculation proceeds as before until either a new coupling station or the right end of the rotor is reached.

Transmitted Force and Pedestal Motion

Let the force transmitted to the pedestal at station n be denoted F. From Eq. (12) it is seen:

$$\text{(45)} \quad \begin{aligned} F_{xc} &= V_{xc,n-1} - V_{xcn} + m_n\omega^2 x_{cn} + \omega^2 U_{xn} \\ F_{xs} &= V_{xs,n-1} - V_{xsn} + m_n\omega^2 x_{sn} - \omega^2 U_{yn} \\ F_{yc} &= V_{yc,n-1} - V_{ycn} + m_n\omega^2 y_{cn} + \omega^2 U_{yn} \\ F_{ys} &= V_{ys,n-1} - V_{ysn} + m_n\omega^2 y_{sn} + \omega^2 U_{xn} \end{aligned}$$

Denoting the amplitude of the pedestal masses x_p and y_p (see Fig. 3) we get:

$$x_p = \frac{F_{xc} - iF_{xs}}{\varkappa_x - M_x\omega^2 + i\omega\delta_x}$$

$$y_p = \frac{F_{yc} - iF_{ys}}{\varkappa_y - M_y\omega^2 + i\omega\delta_y}$$

or

$$\text{(46)} \quad \begin{aligned} x_{pc} &= \frac{F_{xc}(\varkappa_x - M_x\omega^2) - F_{xs}\,\omega\delta_x}{(\varkappa_x - M_x\omega^2)^2 + (\omega\delta_x)^2} \\ x_{ps} &= \frac{F_{xc}\,\omega\delta_x + F_{xs}(\varkappa_x - M_x\omega^2)}{(\varkappa_x - M_x\omega^2)^2 + (\omega\delta_x)^2} \\ y_{pc} &= \frac{F_{yc}(\varkappa_y - M_y\omega^2) - F_{ys}\,\omega\delta_y}{(\varkappa_y - M_y\omega^2)^2 + (\omega\delta_y)^2} \\ y_{ps} &= \frac{F_{yc}\,\omega\delta_y + F_{ys}(\varkappa_y - M_y\omega^2)}{(\varkappa_y - M_y\omega^2)^2 + (\omega\delta_y)^2} \end{aligned}$$

The force transmitted to the base becomes:

$$P_x = \varkappa_x x_p + i\omega\delta_x x_p$$

$$P_y = \varkappa_y y_p + i\omega\delta_y y_p$$

or:

$$
(47)\quad
\begin{aligned}
P_{xc} &= F_{xc} + M_x \omega^2 x_{pc} \\
P_{xs} &= F_{xs} + M_x \omega^2 x_{ps} \\
P_{yc} &= F_{yc} + M_y \omega^2 y_{pc} \\
P_{ys} &= F_{ys} + M_y \omega^2 y_{ps}
\end{aligned}
$$

Energy Balance

Let the relative amplitude between rotor and pedestal mass be $x' = x - x_p$ and $y' = y - y_p$ at a bearing station. Then the energy dissipated in the bearing and the pedestal per revolution becomes:

Energy Dissipated =

$$
(48)\quad
\begin{aligned}
&\pi\{\omega C_{xx}(x_c'^2 + x_s'^2) + \omega C_{yy}(y_c'^2 + y_s'^2) + (\omega C_{xy} + \omega C_{yx})(x_c' y_c' + x_s' y_s') \\
&\quad -(K_{xy} - K_{yx})(x_c' y_s' - x_s' y_c') + \omega\delta_x(x_{pc}^2 + x_{ps}^2) + \omega\delta_y(y_{pc}^2 + y_{ps}^2)\} \\
&+\pi\{\omega D_{xx}(\theta_c'^2 + \theta_s'^2) + \omega D_{yy}(\varphi_c'^2 + \varphi_s'^2) + (\omega D_{xy} + \omega D_{yx})(\theta_c' \varphi_c' + \theta_s' \varphi_s') \\
&\quad -(M_{xy} - M_{yx})(\theta_c' \varphi_s' - \theta_s' \varphi_c') + \omega\delta_x(\theta_{pc}^2 + \theta_{ps}^2) + \omega\delta_y(\varphi_{pc}^2 + \varphi_{ps}^2)\}
\end{aligned}
$$

A summation over all bearings gives the total dissipated energy. At each unbalance station there is an energy input:

$$
(49)\quad \text{Energy Input:}\ \pi\{\omega^2 U_x(x_s - y_c) + \omega^2 U_y(x_c + y_s)\}
$$

Summing over all unbalance stations gives the total energy input which must equal the dissipated energy.

COMPUTER INPUT

The input data is prepared according to the following instructions. Note that, unless specifically stated, no input card may be omitted.

Card 1 and 2: (72 cols. Hollerith) Identification:- Any descriptive text may be punched in cols. 2-72. These two cards must always be included.

Card 3: (10I5) Control parameters -

Word 1. Number of rotor mass stations - The number of mass stations is determined by the above considerations. Also, there must be a mass station at each rotor end, at each bearing, at each unbalance and at

each coupling point. The mass at a station may be zero. The maximum number of mass stations is 80.

Word 2. Number of bearings - This integer denotes the total number of bearings along the rotor. A maximum of 25 bearings is possible.

Word 3. Number of unbalance stations - This integer gives the total number of mass stations at which unbalance is applied. A maximum of 80 unbalance stations is possible.

Word 4. Number of coupling stations - This integer gives the total number of coupling points. It cannot exceed 20.

Word 5. Pedestal flexible/rigid - If this integer is zero, the program assumes the pedestal to be rigid for both translatory and rotational motion and no pedestal data is included. If the integer is 1, the pedestal has flexibility and damping and pedestal data must be provided.

Word 6. Support tilting - If this integer is zero, neither the bearings nor the pedestals resist rotation. In that case, neither the input for the bearing dynamic coefficients for rotational motion nor the pedestal data for rotational motion can be included. If the integer is 1, the bearings and the pedestals have flexibility and damping for rotational motion.

Word 7. Gyroscopic moment - If this integer is zero, no gyroscopic moment is included in the calculation. If gyroscopic moment is desired, the integer should be 1.

Word 8. Number of computations - It was indicated above that the eight bearing parameters were dynamic coefficients and so could account for the variation of parameters with running speed in an approximate manner. However, if a more precise representation of these parameters is desired, these values can be entered each time a new running speed is designated. In order to facilitate this, there is provision in the

program for entering only the bearing or bearing and pedestal data and the corresponding running speed without re-entering the rotor, coupling or unbalance data. Then this word 8 of the control parameters designates the number of sets of parameters which are to be run. If this value is 1, the program assumes that the bearing data is being entered as coefficients of quadratic equations in ω . Note below that the input format of the bearing data differs depending on whether this value is equal to or greater than one.

Word 9. Diagnostic - If this integer is zero, no diagnostic will be performed. A value of 1 will provide the diagnostic output: the diagnostic increases the amount of output a considerable amount and is provided primarily for use in trouble-shooting the program and so this value should alway be zero.

Word 10. Input - If this integer is zero, the program will return to read in a new set of input upon completion of the computation. For the last set of input this value should be 1.

Card 4. (1P4E15.7)

Word 1 is Young' modulus E in lbs/in^2. It is constant throughout the rotor. Since the program never uses E by itself but always in the product EI (I=cross-sectional moment of inertia) any actual variation in E can be absorbed by changing I accordingly.

Word 2 is the scale factor for the determinant in the simultaneous equation subroutine. In general this item is 1.0. It is a factor by which the determinant is multiplied to control computer over/underflow. The simultaneous equation subroutine is used 4 places in the program: once when solving for the unknown end deflections (i.e.Eq.(35)) and 3 times when solving for the unkown slopes in the coupling calculation (i.e. Eq. (42)). If an over/underflow occurs during the calculation the program output will contain: "OVER/UNDERFLOW IN XSIMEQF AT _ _ (integer)" where the value of the integer is 1 to 4. If it is 1, 2 or 3 the error is in the coupling calculation. If it is 4 the error is in solving Eq. (35). Changing the scale-factor may eliminate the trouble.

If the determinant is singular the output gives: "MATRIX IS SINGULAR IN XSIMEQF AT _ _(integer)". If either of the two errors occur the program proceeds with a new rotor speed.

ROTOR DATA

The rotor data will differ depending on whether the effect of the gyroscopic moment is included in the computation. For the case where no gyroscopic moment is included; i.e. where word 7 of card 3 is zero, the rotor data is entered as follows:

Card: (1P3E14.6) - An input card must be given for each mass station. Each card has 3 items.

Word 1 - the mass at the station in lbs.

Word 2 - the length of the shaft section to the right of the station in inches.

Word 3 - the cross-sectional moment of inertia of the shaft section to the right of the station in in^4.

For the last mass station the shaft length and the cross-sectional moment of inertia has no meaning and may be set equal to zero.

If gyroscopic motion is included and word 7, card 3, is not equal to zero, then each card contains two more items in addition to the 3 items indicated just above. Also for this case, the rotor data cards are immediately preceded by a card which contains two values defined as follows:

Card: (I5,1PE23.6). Gyroscopic moment parameters -

Word 1 - Number of iteracions - For each rotor speed the program first calculates the unbalance response without gyroscopic moment. Based on

the thus obtained rotor slopes, the gyroscopic moment is computed and applied to the rotor, resulting in new values of the slope and the process is repeated. The program counts the number of iterations, excluding the calculation without gyroscopic moment. If the count exceeds this input item, the results obtained are printed out, the iteration count is reset to 1 and a new rotor speed calculation starts.

Word 2 - Convergence limit - After each gyroscopic moment iteration, the following relative error is calculated:

$$\frac{|\theta_{c1}^{(K)} - \theta_{c1}^{(K-1)}| + |\theta_{s1}^{(K)} - \theta_{s1}^{(K-1)}| + \text{-----} + |y_{s1}^{(K)} - y_{s1}^{(K-1)}|}{|\theta_{c1}^{(K)}| + |\theta_{s1}^{(K)}| + |\varphi_{c1}^{(K)}| + \text{----} + |y_{s1}^{(K)}|}$$

where $\theta_{c1}, \theta_{s1}, \varphi_{c1}$ and φ_{s1} are the slopes and X_{c1}, X_{s1}, y_{c1} and y_{s1} are the deflections at the left rotor end. The superscript is the iteration number. For each iteration the computer output gives the iteration number and the error. When the error is less than or equal to the input convergence limit, the program prints the results, resets the iteration count to 1 and proceeds with a new rotor speed.

Following this card are the rotor data cards.

Card: (1P5E14.6). An input card is required for each mass station. Each card contains 5 items; the first 3 words are the same as those for the non-gyroscopic moment case above and the remaining two are:

Word 4 - the polar mass moment of inertia in $lbs.in^2$

Word 5 - the transverse mass moment of inertia in $lbs.in^2$

LOCATION OF BEARING SUPPORTS

Card: (14I5). This list provides the numbers of the mass stations at which there is a bearing.

UNBALANCE DATA

Card: (I5, 1P2E15.7). A card is provided for each of the unbalance stations. Each card contains 3 values:

Word 1 - an integer which denotes the number of the mass station at which the unbalance applies.

Word 2 - the cosine component of the unbalance in oz. in.

Word 3 - the sine component of the unbalance in oz. in.

By providing two unbalance components, it is possible to take into consideration the circumferential variation of unbalance along the rotor.

COUPLING DATA

If the rotor does not contain couplings, (Word 4, card 3 is zero), then no coupling data is necessary. If word 4, card 3 is not zero, the following card must be included.

Card: (14I5) - This is a list of integers denoting the mass stations at which there is a coupling.

PEDESTAL DATA

If the pedestal is considered to be infinitely rigid, then no pedestal data is required. In this case word 5, card 3, pedestal flexible/rigid is zero. Otherwise, pedestal data is required. The pedestal data, like the bearing data, is separated into translatory and rotational parameters. Also, as before, the control parameter is the word 6, card 3, support tilting.

Card: (1P6E12.4) - A card must be provided for each bearing. On it are 6 values as follows:

Word 1 - the weight of the pedestal in the X coordinate in lbs.

Word 2 - the pedestal stiffness along the X coordinate in lbs/in.

Word 3 - the pedestal damping along the X coordinate in lbs-sec/in.

Word 4 - same as word 1 but for the ψ coordinate.

Word 5 - same as word 2 but for the ψ coordinate.

Word 6 - same as word 3 but for the ψ coordinate.

If word 6, card 3, support tilting, is not zero, then all of the cards concerned with the translatory parameters are followed by the cards for the rotational parameters. Again there are 6 values on each card as follows:

Word 1 - the mass moment of inertia of the pedestal mass, associated with the X coordinate in lbs.in^2

Word 2 - the pedestal spring coefficient for rotational motion, associated with the X coordinate in lbs-in/rad.

Word 3 - the pedestal damping coefficient for rotational motion, associated with the X coordinate in lbs-in.-sec/rad.

Word 4 - same as word 1 but associated with the ψ coordinate.

Word 5 - same as word 2 but associated with the ψ coordinate.

Word 6 - same as word 3 but associated with the ψ coordinate.

SPEED AND BEARING DATA

Each bearing is represented by 16 dynamic coefficients, 8 for translatory motion and 8 for rotational motion. Of the 8 coefficients, 4 are spring coefficients and 4 are damping coefficients. Since the coefficients in general change with speed, each coefficient is expressed by three components; e.g.

$$K_{xx} = K_{xx,0} + K_{xx,1}\,\omega + K_{xx,2}\,\omega^2$$

where ω is the rotor speed in rad/sec, $K_{xx,0}$ in lbs/in., $K_{xx,1}$ in lbs-sec/in.rad. and $K_{xx,2}$ in lbs-sec^2/in.rad^2. Similar equations hold for the other 15 coefficients. As indicated earlier, if it is desired to enter the bearing data at each value of frequency, there is provision for this in the program.

If word 8, card 3 is 1, the program assumes the bearing data is provided as frequency dependent coefficients. In this case, a card is provided with the speed range and increment and this is followed by the bearing data. An input card is given for each coefficient at each bearing. Each card contains three items, namely the above mentioned three speed components. The sequence of the input cards is: first all the cards for the translatory motion and then all the cards for the rotational motion. The cards for the rotational motion are not required if word 6, card 3, support tilting, is zero. The cards should be given in the following order: $K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}, K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$ for bearing 1, $K_{xx}, \omega C_{xx}$ ------ ωC_{yx} for bearing 2, etc. to the last bearing, then (if word 6, card 3 $\neq$ 0), $M_{xx}, \omega D_{xx}, M_{xy}, \omega D_{xy}, M_{yy}, \omega D_{yy}, M_{yx}, \omega D_{yx}$

for bearing 1, etc. to and including the last bearing.

Card: (1P3E14.6) - Speed data.

Word 1 - initial speed.

Word 2 - final speed.

Word 3 - speed increment.

Card: (1P3E14.6) - Bearing data - in the order defined above with three values on each card as follows:

Word 1 - the coefficient A_0 of the expression $A = A_0 + A_1\omega + A_2\omega^2$

Word 2 - the coefficient A_1 of this expression.

Word 3 - the coefficient A_2 of this expression.

If word 8, card 3, is greater than 1, the program assumes the bearing data will be provided for each value of speed. In this case, a card is provided with a single speed value and this is followed by the bearing data as follows: all of the translatory stiffness and damping coefficients are provided in the order; two cards for each bearing. The first card contains the x coordinate translatory coefficients $K_{xx}, \omega C_{xx}, K_{xy}$ and ωC_{xy} and the second card the y coordinate translatory coefficients $K_{yy}, \omega C_{yy}, K_{yx}$ and ωC_{yx}, both cards for bearing one followed by two cards for bearing two, etc., to the total number of bearings. Again, if word 6, card 3 is zero, no rotational parameters are required, otherwise, they are provided in a similar manner: one card of values $M_{xx}, \omega D_{xx}, M_{xy}, \omega D_{xy}$ and a second card of $M_{yy}, \omega D_{yy}, M_{yx}, \omega D_{yx}$ for bearing 1 followed by two cards each for the remaining bearings.

The card format in this case is then:

Card: (1PE14.6) - Speed.

Card: (1P4E14.6) - Bearing data in the order defined above with these values on each card as follows:

Card 1 - Word 1 - $K_{xx_{1,n}}$

Word 2 - $\omega C_{xx_{1,n}}$

Word 3 - $K_{xy_{1,n}}$

Word 4 - $\omega C_{xy_{1,n}}$

Card 2 - Word 1 - $K_{44_{1,n}}$

Word 2 - $\omega C_{44_{1,n}}$

Word 3 - $K_{4x_{1,n}}$

Word 4 - $\omega C_{4x_{1,n}}$

COMPUTER OUTPUT

The computer output is largely self-explanatory and each output item is identified by a descriptive text. Two sample cases are shown in Appendix A. The output first lists all the input data, i.e. the two heading cards, the control words, Youngs Modulus, the rotor data, the bearing stations, the unbalance data, the coupling stations, the pedestal data, the speed data and finally the bearing data. Thereafter follow the results of the calculations with one set of output for each specified rotor speed. First, the speed is given in RPM which may be followed by the input bearing data if it is new for every speed. Next, a 9 column list gives the rotor amplitude and bending moment at each rotor station. Both the amplitude and the bending moment require four quantities for their description. Since each rotor station whirls in an elliptical orbit it is convenient to express the four quantities in terms of the dimensions of the ellipse. Then the four quantities become:

1. the major axis of the ellipse: a(i.e. the maximum amplitude or the maximum bending moment during one revolution.
2. the minor axis of the ellipse: b
3. the angle between the x-axis of the overall reference system and the major axis of the ellipse: β, degrees (in output identified by: ANGLE X-MAJOR)
4. the phase angle with respect to the cosine-component of the unbalance: α , degrees.

The amplitude is given in thousands of an inch (mils) and the bending moment is given in lbs.in.

The selected method of presentation is illustrated by Fig. 5 and is given in detail in the analysis by Eqs. (37) to (41). However, a general description will also be given here.

The presentation is based on two reference coordinate systems. The first reference system is the stationary x-y system fixed with respect to ground, and which has at each rotor station its origin in the center of the statically deflected rotor (i.e. the deflection due to gravity). The x-y-system is "communicated" to the rotor via the specified values of the bearing spring and damping coefficients

($K_{xx}, K_{xy}, \omega C_{xx}$, etc.) and the corresponding pedestal data. In other words, the directions of the x-axis and the y-axis are chosen when preparing the computer input and the choice reflects in the input values used for K_{xx}, K_{xy} etc. Then the elliptical rotor orbit is centered in the origin of the x-y-system (i.e. the steady state shaft center), it has a major axis a, a minor axis b, and the orientation of the ellipse is defined by the angle β between the x-axis and the major axis, measured in direction of rotor rotation. Note, that both a, b and β vary along the rotor. A negative value for b signifies backward whirl.

Thus a, b and β specify the dimensions and the orientation of the elliptical orbit but one more quantity is needed to specify the position of the moving shaft center on the ellipse at any given time. The phase angle α serves this purpose. Let the major axis be the x_1-axis and the minor axis the y_1-axis (see Fig.5), i.e. the x_1-y_1-system is obtained by rotating the x-y-system an angle β in the direction of rotor rotation. Then the instantaneous position of the shaft center is given by:

$$x_1 = a\cos(\omega t + \alpha)$$
$$y_1 = b\sin(\omega t + \alpha)$$

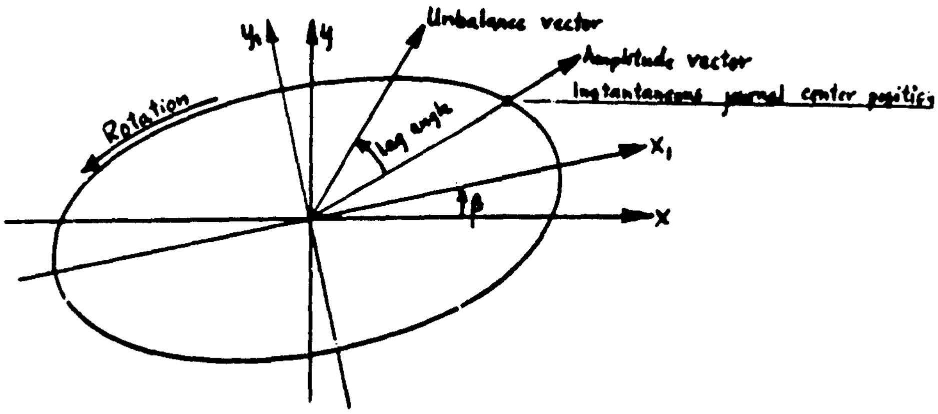
Note that the orientation of the x_1-y_1-system changes along the rotor since β does with respect to the x-y-system the instantaneous shaft center position is given by:

$$x = \sqrt{(a\cos\beta)^2 + (b\sin\beta)^2} \cdot \cos\left(\omega t + \alpha + \tan^{-1}\left(\tfrac{b}{a}\tan\beta\right)\right)$$
$$y = \sqrt{(a\sin\beta)^2 + (b\cos\beta)^2}\ \sin\left(\omega t + \alpha + \tan^{-1}\left(\tfrac{a}{b}\tan\beta\right)\right)$$

In addition to determining the instantaneous position of the shaft center with respect to a stationary coordinate system it also may be desired to know the position with respect to the rotor unbalance. The location of the unbalance in the rotor is defined by a coordinate system which is fixed in the rotating shaft and whose axes are called "the cosine axis" and "the sine axis". Hence, each unbalance consists of two components: a cosine component and a sine component (in the analysis the symbols U_x and U_y are used, respectively, see Eq.s(10) and (11)). The instantaneous orientation of the cosine-system is defined by the angle (ωt) between the fixed axis and the cosine-axis. Thus, the instantaneous phase angle between the amplitude vector (i.e. the radius vector from the center of the elliptical orbit going through the instantaneous shaft center position) and the total rotor unbalance vector is:

angle by which amplitude vector lags unbalance vector =

$$\omega t - \beta + \tan^{-1}\left(\frac{\sum U_{yn}}{\sum U_{xn}}\right) - \tan^{-1}\left(\frac{b}{a}\tan(\omega t + \alpha)\right)$$



Here, $\sum U_{xn}$ and $\sum U_{yn}$ indicates the summations of the cosine-components and the sine-components, respectively, of all unbalances. It is seen that the lag-angle is not constant as the shaft center moves around its orbit. It attains its maximum and minimum values when:

$$\tan^2(\omega t + \alpha) = \frac{a}{b}$$

Although the discussion above is primarily aimed at describing the motion of the shaft center (i.e. the computer output for the amplitude) the same description applies to the output for the bending moment. However, for each rotor station the output lists one line for the amplitude but two lines for the bending moment. Whereas the output for the amplitude applies at the rotor station itself the bending moment has one value immediately to the left of the station and another value immediately to the right of the station. The output gives the left hand value first (i.e. the output gives M_n and M_n' respectively, see Fig. 2). The two values are in general the same unless the particular station is a bearing station which resists tilting. The last listed value of the bending moment should always be zero (i.e. corresponding values of the major and minor axis should be zero). In general they are not exactly zero but very small. The amount by which the values differ from zero gives an indication of the accuracy of the calculation. Note, that for this reason the last values of the angles β and α are meaningless.

Following the output for the amplitude and for the bending moment come tl sults for the force transmitted to the bearing housing (equal to the dyna bearing reaction). If the pedestals are flexible, the force transmitted t the foundation and the amplitude of the pedestal mass are also given. Eac the three quantities are presented in two ways: first in terms of the cor ponding ellipse (i.e. in analogy to the rotor amplitude) and secondly by t x and y-components. Thus, if the transmitted force is F the output gives quantities: the major axis, the minor axis, the orientation angle β, the angle α, $|F_x|$, α_x, $|F_y|$ and α_y where the last four items are defi

$$\text{force in x-direction: } F_x = |F_x| \cos(\omega t + \alpha_x)$$

$$\text{force in y-direction: } F_y = |F_y| \sin(\omega t + \alpha_y)$$

The transmitted force is given in lbs and the pedestal amplitude in thousar of an inch (mils).

The next line of output serves as a check on the calculation. It gives the energy per revolution put into the system by the unbalance forces and the e dissipated per revolution in the bearings and pedestals. Theoretically, th two values should be equal but numerical inaccuracies in the calculations a cause discrepancy. Normally they differ in the fifth or sixth decimal plac The energy is given in lbs.inch/revolution.

To convert it into HP multiply the energy value by the speed in RPM and divi by $3.96 \cdot 10^5$.

If the input does not include any gyroscopic moment effects the calculations repeated for a new rotor speed and the output will follow the description gi above. If the gyroscopic moment is included there are two sets of output fo each rotor speed, each set having the format as explained above. The first applies to a rotor without any gyroscopic moments, and the second set give the final result for the calculation with the gyroscopic moment included. T

two sets are separated by a two column list giving the sequential results of the iterations needed to perform the gyroscopic moment calculation. The first column identifies the iteration number and the second column gives the relative convergence of the iteration procedure as explained in describing the computer input.

COMPUTER PROGRAM: THE STABILITY OF A ROTOR IN FLUID FILM BEARINGS

This section sets forth the basic analysis and the detailed instructions for using the computer program: PN0017: "The Stability of a Rotor in Fluid Film Bearings" for the IBM 704 digital computer. The program calculates the speed at onset of instability (the threshold speed) and the corresponding whirl frequency.

Each rotor support consists of a fluid film bearing mounted in a pedestal, both members possessing flexibility and damping. The bearing fluid film is represented by 8 dynamic coefficients and it is the value of these coefficients which primarily govern the instability mechanism. For a given application they vary with the speed of the rotor and they must be specified in the computer input for each speed to be tested. The bearing pedestals are represented by 2 spring coefficients and 2 damping coefficients (in the vertical and the horizontal direction, respectively) and the corresponding masses may also be given.

The program is to a large extent compatible with the unbalance response program such that much of the input data used in the latter program also applies to the stability program.

THEORETICAL ANALYSIS

The analysis is an extension of the methods used in the previous section to determine the unbalance response of the rotor. Thus, the following discussion assumes familiarity with the earlier given analysis. The rotor is again represented by a finite number of mass stations connected by weightless but stiff shaft sections which can be brought to approximate the actual rotor to any degree of accuracy depending on the number of mass stations. Each bearing is represented by 8 dynamic coefficients: K_{xx}, C_{xx}, K_{xy}, C_{xy}, K_{yx}, C_{yx}, K_{yy} and C_{yy}, which depend on the operating speed of the rotor: ω, radians/sec.

The purpose of the analysis is to establish the onset of instability of the rotor-bearing system. No external forces act on the rotor (i.e. there are no unbalance forces), instead the dynamical equilibrium of the steady-state operation of the

system is tested for a series of discrete speed values over a speed range. This is done by disturbing the rotor with an assigned frequency ν radians/sec. To this end the previously established equations are used as summarized in Eqs.(32) by replacing ω with ν or since ω is given, the disturbing frequency is specified as a ratio of the speed:

$$\frac{\nu}{\omega} \qquad \text{(note: } \nu = \left(\frac{\nu}{\omega}\right)\omega \text{)}$$

The rotor unbalance components U_{xn} and U_{yn} are eliminated. Applying Eqs.(32) and the boundary conditions Eqs. (33) and (34) yields Eq.(35) where the right hand side is now equal to zero.

Since the assigned frequency is a pure frequency and does not contain a transient term the outlined procedure applies to the threshold of instability. In other words, the calculation determines the state of neutral stability at which the effect of any disturbance continues indefinitely without either increasing or decreasing. Hence, at the point of neutral stability there must be a finite, although undetermined, solution for the rotor amplitudes, i.e. the 8 end values, θ_{c1}, θ_{s1}, ..., y_{s1} cannot all vanish. This implies that the determinant on the left hand side of Eq.(35) must be zero for the system to be neutrally stable.

On this basis, a calculation procedure can be devised. Select a sufficiently low value of the rotor speed that the system is known to be stable and scan the entire frequency range to obtain the value of the determinant for each frequency. Repeat the calculations for an increased rotor speed and proceed in this way until a speed is encountered at which the determinant becomes zero. At that particular speed the rotor-bearing system is on the threshold of instability and any further increase in the rotor speed will make the system unstable.

Although the method is quite simple in principle certain difficulties arise in applying the method. Considering the matrix in Eq.(35) it is seen to be an 8 by 8 matrix in which all elements are real. Actually, it can be written as a 4 by 4 matrix with complex elements. Therefore, its determinant will always be positive and in applying the outlined calculation procedure the zero-point of the determinant will appear as a minimum. There will be no cross-over from a positive value to a negative value, or, in other words, at the onset of

instability the chosen form of the determinant has a repeated root. Thus, it is necessary to plot the determinant as a function of the rotor speed to be able to establish when it becomes zero. However, the determinant also depends on the disturbing frequency and it only vanishes for a particular value of that frequency. It is, therefore, also necessary to know the frequency-value at which the determinant should be evaluated at each rotor speed.

For this reason it is chosen to calculate the real and imaginary part of the 4 by 4 complex determinant which is equivalent to the 8 by 8 real determinant. Denote the real matrix:

$$B_{2n} = \begin{Bmatrix} b_{11} & \cdots & b_{1,2n} \\ \vdots & & \\ b_{2n,1} & \cdots & b_{2n,2n} \end{Bmatrix} \qquad \text{(n = 4 in the present case)}$$

and let the corresponding complex matrix by:

$$A_n = \begin{Bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & & \\ a_{n1} & \cdots & a_{nn} \end{Bmatrix} \qquad \text{(n = 4 in the present case)}$$

With the convention followed in the present analysis the two matrices are related by:

$$b_{11} = \text{Re}\{a_{11}\} \qquad b_{12} = \text{Im}\{a_{11}\}$$
$$b_{21} = -\text{Im}\{a_{11}\} \qquad b_{22} = \text{Re}\{a_{11}\}$$

etc.

Let these matrices be the coefficient matrices in a set of linear equations:

(50) $$B_{2n} \cdot X = U$$

(51) $$A_n \cdot Z = W$$

where:

$$X = \begin{Bmatrix} x_1 \\ y_1 \\ x_2 \\ \vdots \\ y_n \end{Bmatrix} \qquad U = \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ \vdots \\ v_n \end{Bmatrix} \qquad Z = \begin{Bmatrix} z_1 \\ z_2 \\ \vdots \\ z_n \end{Bmatrix} \qquad W = \begin{Bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{Bmatrix}$$

such that:

$$z_j = x_j - iy_j \qquad j = 1,n$$

$$w_j = u_j - iv_j \qquad j = 1,n$$

Since the two equations are equivalent they must yield the same solution. Therefore, first set: $w_1 = w_2 = \cdots = w_{n-1} = 0$ and $w_n = i$ which means: $u_1, u_2 \cdots u_n = 0$, $v_1 = v_2 = \cdots = v_{n-1} = 0$ and $v_n = -1$. Solve Eq.(51) for z_n:

(52)
$$z_n = \frac{i\bar{A}_{n-1}}{\bar{A}_n} = \frac{i\bar{A}_{n-1}(\Delta_{nr} - i\Delta_{ni})}{\Delta_{nr}^2 + \Delta_{ni}^2}$$

where $\bar{A}_n$ is the determinant of A_n, $\bar{A}_{n-1}$ is the determinant of A_n with the n'th column and row removed, and:

$$\Delta_{nr} + i\Delta_{ni} = \bar{A}_n$$

i.e., Δ_{nr} and Δ_{ni} are the real and imaginary parts,respectively of the complex matrix and it is desired to calculate them.

Next, solve Eq.(50) for x_n and y_n with $v_n = -1$:

(53)
$$x_n = -\frac{\bar{B}'_{2n-1}}{\bar{B}_{2n}}$$

(54)
$$y_n = \frac{-\bar{B}_{2n-1}}{\bar{B}_{2n}}$$

where $\bar{B}_{2n}$ is the determinant of B_{2n}, $\bar{B}_{2n-1}$ is the determinant of B_{2n} with the n'th column and row removed, and $\bar{B}'_{2n-1}$ is the determinant of B_{2n} with the (n-1)'th column and the n'th row removed. Furthermore, it is known that:

$$\bar{B}_{2n} = |\bar{A}_n|^2 = \Delta_{nr}^2 + \Delta_{ni}^2$$

Equate Eqs. (52), (53) and (54) to get:

$$\frac{i\bar{A}_{n-1}(\Delta_{nr} - i\Delta_{ni})}{\Delta_{nr}^2 + \Delta_{ni}^2} = \frac{\bar{B}'_{2n-1} + i\bar{B}_{2n-1}}{\Delta_{nr}^2 + \Delta_{ni}^2}$$

or:

(55)
$$\Delta_{nr} - i\Delta_{ni} = \frac{\bar{B}_{2n-1} - i\bar{B}'_{2n-1}}{\bar{A}_{n-1}} = \frac{\bar{B}_{2n-1} - i\bar{B}'_{2n-1}}{\bar{B}_{2n-2}}(\Delta_{n-1,r} - i\Delta_{n-1,i})$$

where $\overline{B}_{2n-2}$ is the determinant of B_{2n} with the two last columns and rows deleted and:

$$\Delta_{n-1,r} + i\,\Delta_{n-1,i} = \overline{A}_{n-1}$$

Thus, Eq.(55) gives a recurrence formula where the order of the original determinant is reduced by 1. If it is applied repeatedly the final result becomes:

(56) $$\Delta_{nr} - i\,\Delta_{ni} = \prod_{k=1}^{n} \frac{\overline{B}_{2k-1} - i\,\overline{B}'_{2k-1}}{\overline{B}_{2k-2}}$$

with the definition:

$$\overline{B}_0 = 1$$

and:

(57) $\overline{B}_{2k-1}$ is the determinant corresponding to the first (2k-1) columns and rows of the matrix B_{2n}

(58) $\overline{B}'_{2k-1}$ is the determinant corresponding to the first (2k-1) columns and rows of the matrix B_{2n} but where the (2k-1)'th column has been interchanged with the 2k'th column.

(59) B_{2k-2} is the determinant corresponding to the first (2k-2) columns and rows of the matrix B_{2n}.

Thus a method has been established to calculate the real and imaginary part of an n by n complex determinant. The method is used to evaluate the determinant of the 8 by 8 matrix in Eq. (35).

It may be noted that Eq. (35) and Eq. (50) are identical except for the change in nomenclature. Hence, in Eq. (50) X represents the 8 rotor end coordinates: θ_{cl}, θ_{sl}, ..., y_{cl}, y_{sl} and V represents the moment and shear components at the other end of the rotor: M_{xcr}, M_{xsr}, ..., V_{ycr}, V_{ysr}. Eq. (50) is solved in Eqs. (53) and (54) for the case of $v_n = -1$, i.e. for $V_{ysr} = -1$ which means that a force:

$$force = -\sin \nu t$$

has been applied to the rotor end. The corresponding amplitude at the same rotor end can be computed as described in the rotor response analysis. Let the y-component be: $\text{amplitude} = y_{cr} \cos \nu t + y_{sr} \sin \nu t$

The energy input imparted to the rotor motion is:

$$\text{(60)} \qquad \text{Energy per cycle} = \int_0^{2\pi} -\sin\nu t\,(-\nu y_{kr}\sin\nu t + \nu y_{sr}\cos\nu t)\,dt = \pi y_{cr}$$

A positive energy input implies that energy is required to sustain the particular vibratory motion, i.e. the motion is stable. On the other hand, a negative energy input signifies an unstable motion. When the energy input is zero the motion is neutrally stable. It must be noted that the motion itself may not be possible unless the previously discussed determinant is also zero, i.e. the outlined energy criterion can not be used alone to test the stability of the rotor-bearing system. However, the criterion can be used to determine the value of the instability frequency.

A simple example may serve as an illustration. Let a single mass M be supported on a spring with a coefficient K and a dashpot coefficient C. The amplitude is:

$$y_c\cos\nu t + y_s\sin\nu t$$

Apply a force V_{ys} sin νt such that the equations of motion become:

$$\begin{Bmatrix} (K-M\nu^2) & \nu C \\ -\nu C & (K-M\nu^2) \end{Bmatrix} \begin{Bmatrix} y_c \\ y_s \end{Bmatrix} = \begin{Bmatrix} 0 \\ V_{ys} \end{Bmatrix}$$

in analogy to Eq. (35). The determinant becomes:

$$(K-M\nu^2)^2 + (\nu C)^2$$ (note: the determinant is always positive)

which vanishes when $\nu C = 0$ and $\nu^2 = K/M$, i.e. the frequency must be such that it simultaneously makes the damping νC zero and also equals the natural frequency of the system. Next, solving for y_c and computing the energy input yields:

$$\text{Energy input per cycle} = -\pi V_{ys} y_c = \pi V_{ys}^2 \frac{\nu C}{(K-M\nu^2)^2 + (\nu C)^2}$$

Applying the energy criterion from above the motion is unstable when νC is negative and vice versa, which is of course evident in this simple case. However, the system is only <u>neutrally</u> stable if in addition the frequency also equals the natural frequency: $\nu = \frac{K}{M}$.

In calculating the energy input from Eq.(60) it is seen that a difficulty arises when the system determinant is equal to zero in which case the amplitude y_{cr} cannot be determined. To circumvent this problem, y_{cr} is not computed as its actual value. In evaluating θ_{c1}, θ_{s1}.....y_{s1} from Eq. (35) with $V_{ysr} = -1$, Cramer's rule is used but such that the system determinant is always set equal to 1 regardless of its true value. Thus, the resulting calculated energy should actually be divided by the system determinant to obtain the real value of the energy input.

To solve for the onset of instability the procedure is:

a. Select a rotor speed sufficiently small that the system is known to be stable.

b. Scan the frequency range and determine those frequency values at which the real part and the imaginary part of the system determinant equal zero.

c. Repeat the calculation for several values of the rotor speed covering a sufficiently large speed range.

d. Plot curves of frequency versus rotor speed, obtaining one (or more) curve corresponding to the real part of the determinant being zero and one (or more) curve corresponding to the imaginary part being zero. The intersection of the curves determines the threshold speed.

To assist in searching for the instability frequency the single bearing frequency value is determined for each bearing. This value is derived by considering a stiff, symmetric rotor supported in similar bearings. Let the rotor mass per bearing be M whereby the equations of motion becomes:

$$\begin{Bmatrix} (K_{xx}-M\nu^2+i\nu C_{xx}) & (K_{xy}+i\nu C_{xy}) \\ (K_{yx}+i\nu C_{yx}) & (K_{yy}-M\nu^2+i\nu C_{yy}) \end{Bmatrix} \begin{Bmatrix} x \\ y \end{Bmatrix} = 0 \qquad (61)$$

The real and the imaginary parts of the determinant have to equal zero separately:

$$(K_{xx}-M\nu^2)(K_{yy}-M\nu^2)-K_{xy}K_{yx}-\nu^2(C_{xx}C_{yy}-C_{xy}C_{yx})=0 \qquad (62)$$

$$(K_{xx}-M\nu^2)C_{yy}+(K_{yy}-M\nu^2)C_{xx}-K_{xy}C_{yx}-K_{yx}C_{xy}=0 \qquad (63)$$

Solve the equations to get:

$$\left(\frac{\nu}{\omega}\right)^2 = \frac{(K_{xx}-M\nu^2)(K_{yy}-M\nu^2)-K_{xy}K_{yx}}{\omega C_{xx}\,\omega C_{yy}-\omega C_{xy}\,\omega C_{yx}} \tag{64}$$

$$M\nu^2 = \frac{K_{xx}\,\omega C_{yy}+K_{yy}\,\omega C_{xx}-K_{xy}\,\omega C_{yx}-K_{yx}\,\omega C_{xy}}{\omega C_{xx}+\omega C_{yy}} \tag{65}$$

Computing Eq. (65) first and substituting into Eq. (64) yields the instability frequency ratio $\frac{\nu}{\omega}$ for the bearing. Since for the actual rotor the bearing reactions are in general unequal and the 8 bearing coefficients, therefore, differ in value among the bearings the instability frequency will not have the same value for all the bearings. However, the instability frequency for the rotor-bearing system will lie between the minimum and maximum value of the bearing frequencies.

COMPUTER INPUT

The input data is prepared according to the instructions given in the following. Note, that unless stated otherwise no input card may be omitted.

Card 1 FORMAT (49 cols. Hollerith) Any descriptive text, used to identify the particular calculation, may be punched in cols. 2-49.

Card 2 FORMAT (6I5) Control parameters:

Word 1 (NS) Number of rotor mass stations. The number of stations is selected according to the previous discussion. There must be a mass station at each rotor end and at each bearing. The mass at a station may be zero. The maximum number of stations is 30.

Word 2 (NB) Number of bearings. This integer denotes the total number of bearings along the rotor. A maximum of 10 bearings is allowed.

Word 3 (NFR) Number of frequency ratios. This integer specifies the number of items in the input list for the frequency ratios.

Word 4 (NCAL) Number of speed and bearing data input sets. Each set of data consists of a speed range and the values of the 8 dynamic coefficients for each bearing. The speed range is specified by an initial speed, a final speed and a speed increment. For each speed value in the speed range the frequency range is scanned and the corresponding values of the system determinant are calculated. There is no limitation on the value of the input item.

Word 5 (NPST) Pedestal flexible/rigid. If this integer is zero the program assumes the pedestals to be rigid and no pedestal data can be furnished. If the integer is 1 the pedestal has both flexibility and damping and the pedestal data must be given.

Word 6 (INP) Input. If this integer is zero the program will return to read in a new set of input upon completion of the computation. For the last set of input the integer should be 1.

Card 3: FORMAT (1XE13.6)

This card contains a single word, Youngs modulus E in lbs/in^2. It is constant throughout the rotor. Since the program never uses E by itself but always in the product EI (I = cross-sectional moment of inertia) any actual variation in E can be absorbed in a corresponding change of I.

Rotor Data: FORMAT (4(1XE13.6))

The rotor data consist of as many cards as there are mass stations (card 2, word 1). Each card has 4 words:

Word 1: the mass at the station in lbs.

Word 2: the length of the shaft section to the right of the station in inches

Word 3: the cross-sectional moment of inertia of the shaft section to the right of the station in in^4.

Word 4: the polar mass moment of inertia minus the transverse mass moment of inertia, $lbs.in^2$.

For the last mass station the shaft length and the cross-sectional moment of inertia has no meaning and may be set equal to zero.

LOCATION OF BEARING SUPPORTS: FORMAT (10(1XI4))

This list of integers provides the number of each mass station at which there is a bearing. The stations should be listed in sequence, beginning with the lowest number.

PEDESTAL DATA: FORMAT (6(1XE11.4))

If the pedestals are rigid no pedestal data are required and item 5, card 2, must be zero. Otherwise, the data for each pedestal must be provided. There is one card for each pedestal and they should be in the same sequence as the bearing station numbers in the previous list. Each card contains 6 words:

Word 1: the vibratory mass of the pedestal for motion in the x-direction, lbs.

Word 2: the pedestal stiffness in the x-direction, lbs/in

Word 3: the pedestal damping coefficient in the x-direction, lbs.sec/in

Word 4: the vibratory mass of the pedestal for motion in the y-direction, lbs.

Word 5: the pedestal stiffness in the y-direction, lbs/in

Word 6: the pedestal damping coefficient in the y-direction, lbs.sec/in

LIST OF FREQUENCY RATIO VALUES: FORMAT (4(1XE13.6))

This input list gives the values of the frequency ratio $\frac{\nu}{\omega}$ at which the program evaluates the system determinant (ν = disturbance frequency, radians/sec, ω = angular speed of rotor, radians/sec). The values should be given in descendir order, for instance: $\frac{\nu}{\omega}$ = .55, .50, .49, .45, .40 ...... The program automat inserts in the list the "eigen-instability" frequency ratio from each bearing determined from Eqs. (64) and (65). In most cases these values are equal to a ximately .5 but may be less for heavily loaded bearings. Unfortunately, the " instability" frequency ratio is very sensitive to even small deviations in the dynamic bearing coefficients from their accurate values. It is, therefore, re commended that the input values of the bearing coefficients be checked beforeh by means of Eqs. (64) and (65). If the thus calculated frequency ratio value differs much from .5 the bearing coefficients should be checked.

ROTOR SPEED AND BEARING DATA

The following input data should be repeated as many times as specified by word card 2. First comes a card giving the speed range for the calculations. The speed range is defined by an initial speed value, a final speed value and a sp increment, all in RPM. Thus, if the initial speed is given as 3000 RPM, the fi speed as 9000 RPM, and the speed increment as 1000 RPM calculations are perfor for 3000, 4000, 5000, 6000, 7000, 8000 and 9000 RPM.

Next follows the 8 dynamic coefficients for each bearing. There are 4 values per card, hence, there are 2 cards per bearing. The first card gives K_{xx}, ωC_{x} K_{xy} and ωC_{xy}, and the second card gives K_{yy}, ωC_{yy}, K_{yx} and ωC_{yx}. All the coefficients are measured in lbs/inch. The cards should be given in the same sequence as the bearing station numbers in the previous input list.

COMPUTER OUTPUT

An example of the output is included in Appendix B.

The first page of the output lists the input values for checking and control pu poses. Next, follows the results of the calculations with the results for each rotor speed given separately. The first line specifies the particular speed

and then follows the "eigen" - instability frequency in RPM and the "eigen" - mass in lbs for each bearing as determined from Eqs. (64) and (65). They are labeled: "INST.FREQ, RPM" and "INST.WEIGHT", respectively. Thereafter the results of the calculations for each frequency are listed in 5 columns. The first column, labeled "FREQ.RAT.", gives the frequency ratio $\frac{\nu}{\omega}$. The second column, labeled "DETERMINANT", gives the square root of the system determinant (i.e. of the matrix in Eq. (35)). The third and the fourth columns, labeled "RE(DET)" AND "IM(DET)" gives the real and the imaginary part of the system determinant, respectively (i.e. Δ_{nr} and Δ_{ni} from Eq. (56)). The last column, labeled "ENERGY", is proportional to the energy input given by Eq. (60).

It should be noted that in order to determine if the rotor is stable or unstable it is necessary to find at which speed it becomes unstable. Hence, results must be available over a range of speeds. To determine that speed, at which instability sets in, the results must be plotted. One method is as follows: for each speed, plot the real and imaginary part of the system determinant against the frequency ratio. Find those frequency ratio values at which the two functions become zero, (there are usually several values). Next, plot the "zero-point" frequency ratios against the rotor speed, obtaining a curve corresponding to the imaginary part of the determinant. Where the two curves intersect is the threshold speed. Thus, for the output example given in Appendix B the threshold speed is found to be 8,350 RPM at a frequency ratio of .4937.

ACKNOWLEDGMENT

The analyses and the computer program described in the present report are developed from two basic computer programs which resulted from an internal research program by Mechanical Technology Inc.

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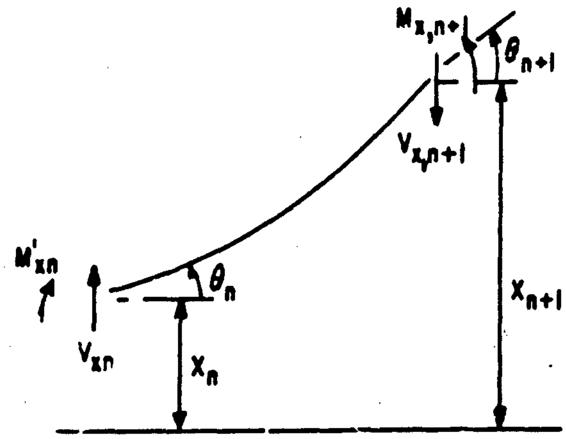

FIG. 1 SHAFT SECTION BETWEEN TWO MASS STATIONS

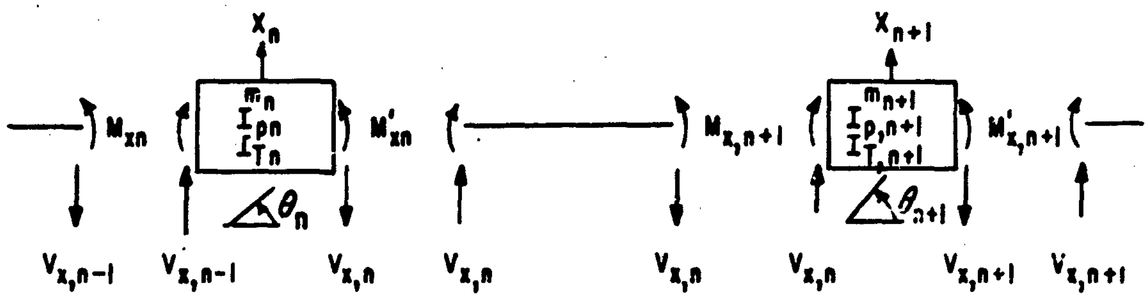

FIG. 2 CONVENTION AND NOMENCLATURE FOR ROTOR CALCULATION

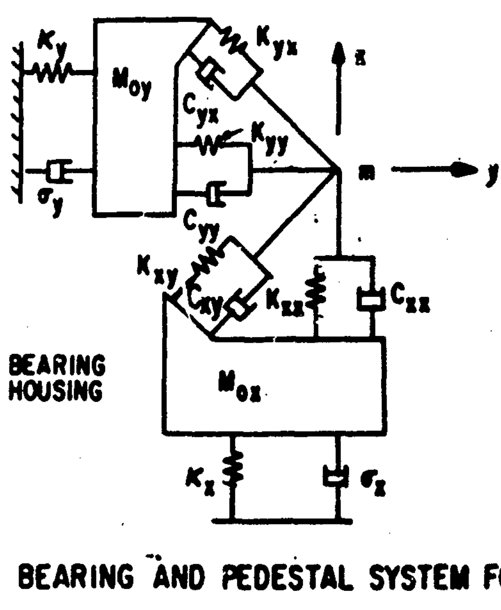

FIG. 3 BEARING AND PEDESTAL SYSTEM FOR TRANSLATORY MOTION

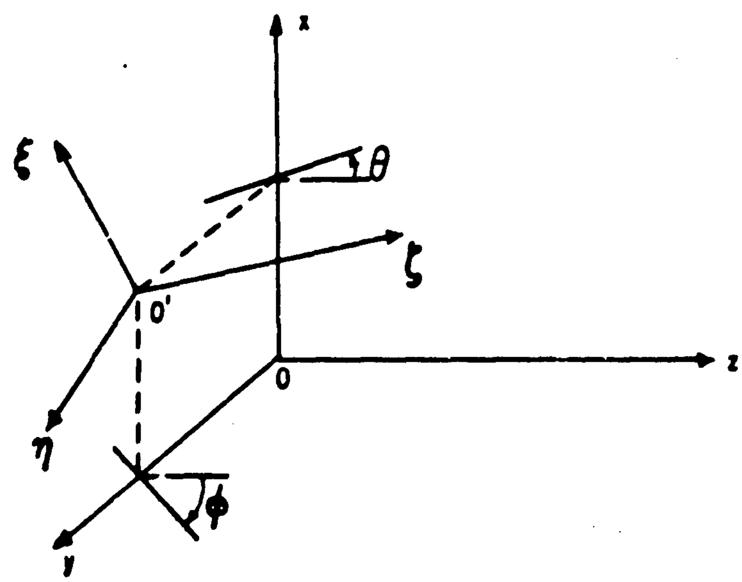

FIG. 4 GYROSCOPIC MOMENT CALCULATION

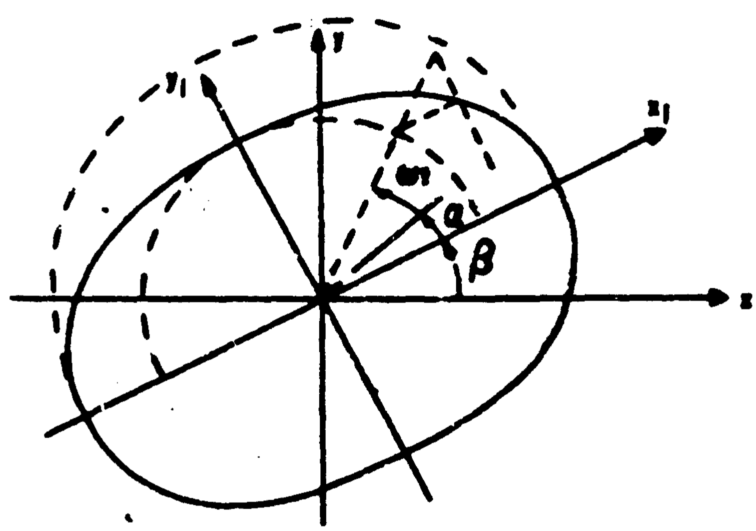

FIG. 5 ELLIPTICAL WHIRL PATH

APPENDIX A

SAMPLE CALCULATIONS AND INPUT FORMS FOR THE COMPUTER PROGRAM "UNBALANCE RESPONSE OF A ROTOR IN FLUID FILM BEARINGS"

```
$JOB           0,5,5000       65-341,FREEMAN,SESCD
$IHJOB FREMAN  FIOCS,MAP
$IBFTC ROTOR   M94,XR7,NODECK,LIST
C     MECHANICAL TECHNOLOGY,INC.       JORGEN W. LUND
C     IUNBALANCE RESPONSE OF ROTOR IN NON-UNIFORM BEARINGS  PN0011
      DIMENSION BMXC(10, 80),BMXS(10, 80),BMYC(10, 80),BMYS(10, 80),VXC
     1(10,41),VXS(10,41),VYC(10,41),VYS(10,41),DXC(10,40),DXS(10,40),DYC
     2(10,40),DYS(10,40),XC(10,40),XS(10,40),YC(10,40),YS(10,40),DMXA(40
     3),DMXB(40),DMXC(40),DMXD(40),DMYA(40),DMYB(40),DMYC(40),DMYD(40),
     4DVXA(40),DVXB(40),DVXC(40),DVXD(40),DVYA(40),DVYB(40),DVYC(40),
     5DVYD(40),RM(40),RL(40),RS(40),RIP(40),RIT(40),DIA(40),DIB(40),DIC(
     640),DID(40),AN(40),BN(40),DN(40),UX(40),UY(40),LU(40),LB(25),BKXX(
     73,25),BCXX(3,25),BKXY(3,25),BCXY(3,25),BKYY(3,25),BCYY(3,25),BKYX(
     83,25),BCYX(3,25),BSMXX(3,25),BDMXX(3,25),BSMXY(3,25),BDMXY(3,25),
     9BSMYY(3,25),BDMYY(3,25),BSMYX(3,25),BDMYX(3,25)
      DIMENSION PMX(25),PMY(25),PKX(25),PCX(25),PKY(25),PCY(25),PIX(25),
     1PIY(25),PSMX(25),PDMX(25),PSMY(25),PDMY(25),LC(20),A(8,8),B(8,4),
     2C(8,4),D(8,1),F(4,4,20),CFM(8,8),ENT(10),RHS(8,1),DVUX(80),
     3 DVUY(80),DUMMY(300),SHA(3),SHB(3),SHC(3),SHD(3),AUX(25,4,3),
     4BUX(25,4,3),DUM1(100),CLNR(8)
      COMMON  A       , B       , C       , D       , CFM     , ENT
      COMMON  RHS     , DUM1    , CF9     , MAT     , KFN     , CLNR
      COMMON  PRN3
      COMMON NS,NB,MU,NC,NPST,NMOM,NGYR,NCAL,NDIAG,INPUT,YM,SCF,RM,RL,
     1RS,NIT,DGYR,RIP,RIT,LB,LU,UX,UY,LC,PMX,PKX,PCX,PMY,PKY,PCY,KST,
     2PIX,PSMX,PDMX,PIY,PSMY,PDMY,SPST,SPFN,SPINC,BKXX,BCXX,BKXY,BCXY,
     3BKYY,BCYY,BKYX,BCYX,BSMXX,BDMXX,BSMXY,BDMXY,BSMYY,BDMYY,BSMYX,
     4BDMYX,CF1K,CF1C,CF1D,CF1E,CF2K,CF2C,CF2D,CF2E,CF2A,CF2B,CF2M,CF2N,
     5CF1A,CF1B,CF1M,CF1N,CF1,CF2,CF3,CF4,CF5,CF6,CF7,CF8,STF,ANSP2,
     6ANSP,SPCAL,DVXA,DVXB,DVXC,DVXD,DVYA,DVYB,DVYC,DVYD,DMXA,DMXB,DMXC,
     7DMXD,DMYA,DMYB,DMYC,DMYD,AN,BN,DN,III
      COMMON BMXC,BMXS,BMYC,BMYS,VXC,VXS,VYC,VYS,DXC,DXS,DYC,DYS,XC,XS,
     1YC,YS,DIA,DIB,DIC,DID,DVUX,DVUY,DUMMY,SHA,SHB,SHC,SHD,AUX,BUX
      COMMON JCAL,AMS,NITC
  201 III=1
  200 CALL SUBR
C                      ROTOR CALCULATION
  400 CF1=0.0
      CF2=0.0
      CF3=0.0
      CF4=0.0
      CF5=0.0
      CF6=0.0
      CF7=0.0
      CF8=0.0
      NITC=1
      IST=1
      IFN=9
  401 JST=1
      NCC=1
      IF(NC) 403,403,402
  402 JFN=LC(1)
      GO TO 404
  403 JFN=NS
  404 DO 405 J=1,NS
      DVUX(J)=0.0
  405 DVUY(J)=0.0
      DO 422 I=IST,IFN
      KST=1
      IF(JST-1) 411,411,406
  406 KFN=JST+JST
      BMXC(I,KFN)=0.0
      BMXS(I,KFN)=0.0
```

```
      BMYC(I,KFN)=0.0
      BMYS(I,KFN)=0.0
      DXC(I,JST)=0.0
      DXS(I,JST)=0.0
      DYC(I,JST)=0.0
      DYS(I,JST)=0.0
      GO TO (407,408,409,410,418,418,418,418,416,418),KST
  407 DXC(1,JST)=1.0
      GO TO 418
  408 DXS(2,JST)=1.0
      GO TO 418
  409 DYC(3,JST)=1.0
      GO TO 418
  410 DYS(4,JST)=1.0
      GO TO 418
  411 BMXC(I,1)=0.0
      BMXS(I,1)=0.0
      BMYC(I,1)=0.0
      BMYS(I,1)=0.0
      VXC(I,1)=0.0
      VXS(I,1)=0.0
      VYC(I,1)=0.0
      VYS(I,1)=0.0
      XC(I,1)=0.0
      XS(I,1)=0.0
      YC(I,1)=0.0
      YS(I,1)=0.0
      DXC(I,1)=0.0
      DXS(I,1)=0.0
      DYC(I,1)=0.0
      DYS(I,1)=0.0
      GO TO (407,408,409,410,412,413,414,415,416,418),KST
  412 XC(5,1)=1.0
      GO TO 418
  413 XS(6,1)=1.0
      GO TO 418
  414 YC(7,1)=1.0
      GO TO 418
  415 YS(8,1)=1.0
      GO TO 418
  416 DO 417 J=1,NU
      KST=LU(J)
      DVUX(KST)=UX(J)*ANSP2
  417 DVUY(KST)=UY(J)*ANSP2
  418 DO 422 J=JST,JFN
      KST=J+J
      KFN=KST-1
      KMD=KST+1
      IF(JST-1) 420,420,419
  419 IF(J-JST) 421,421,420
  420 BMXC(I,KST)=BMXC(I,KFN)+DMXA(J)*DXC(I,J)+DMXB(J)*DXS(I,J)+DMXC(J)*
     1DYC(I,J)+DMXD(J)*DYS(I,J)+DIA(J)
      BMXS(I,KST)=BMXS(I,KFN)-DMXB(J)*DXC(I,J)+DMXA(J)*DXS(I,J)-DMXD(J)*
     1DYC(I,J)+DMXC(J)*DYS(I,J)+DIB(J)
      BMYC(I,KST)=BMYC(I,KFN)+DMYC(J)*DXC(I,J)+DMYD(J)*DXS(I,J)+DMYA(J)*
     1DYC(I,J)+DMYB(J)*DYS(I,J)+DIC(J)
      BMYS(I,KST)=BMYS(I,KFN)-DMYD(J)*DXC(I,J)+DMYC(J)*DXS(I,J)-DMYB(J)*
     1DYC(I,J)+DMYA(J)*DYS(I,J)+DID(J)
      VXC(I,J+1)=VXC(I,J)+DVXA(J)*XC(I,J)-DVXB(J)*XS(I,J)-DVXC(J)*YC(I,J
     1)-DVXD(J)*YS(I,J)+DVUX(J)
      VXS(I,J+1)=VXS(I,J)+DVXB(J)*XC(I,J)+DVXA(J)*XS(I,J)+DVXD(J)*YC(I,J
     1)-DVXC(J)*YS(I,J)-DVUY(J)
      VYC(I,J+1)=VYC(I,J)-DVYC(J)*XC(I,J)-DVYD(J)*XS(I,J)+DVYA(J)*YC(I,J
```

```
     1)-DVYB(J)*YS(I,J)+DVUY(J)
      VYS(I,J+1)=VYS(I,J)+DVYD(J)*XC(I,J)-DVYC(J)*XS(I,J)+DVYB(J)*YC(I,J
     1)+DVYA(J)*YS(I,J)+DVUX(J)
      IF(JFN-J) 422,422,421
  421 BMXC(I,KMD)=BMXC(I,KST)+RL(J)*VXC(I,J+1)
      BMXS(I,KMD)=BMXS(I,KST)+RL(J)*VXS(I,J+1)
      BMYC(I,KMD)=BMYC(I,KST)+RL(J)*VYC(I,J+1)
      BMYS(I,KMD)=BMYS(I,KST)+RL(J)*VYS(I,J+1)
      DXC(I,J+1)=DXC(I,J)+AN(J)*BMXC(I,KST)+BN(J)*VXC(I,J+1)
      DXS(I,J+1)=DXS(I,J)+AN(J)*BMXS(I,KST)+BN(J)*VXS(I,J+1)
      DYC(I,J+1)=DYC(I,J)+AN(J)*BMYC(I,KST)+BN(J)*VYC(I,J+1)
      DYS(I,J+1)=DYS(I,J)+AN(J)*BMYS(I,KST)+BN(J)*VYS(I,J+1)
      XC(I,J+1)=XC(I,J)+RL(J)*DXC(I,J)+BN(J)*BMXC(I,KST)+DN(J)*VXC(I,J+1
     1)
      XS(I,J+1)=XS(I,J)+RL(J)*DXS(I,J)+BN(J)*BMXS(I,KST)+DN(J)*VXS(I,J+1
     1)
      YC(I,J+1)=YC(I,J)+RL(J)*DYC(I,J)+BN(J)*BMYC(I,KST)+DN(J)*VYC(I,J+1
     1)
      YS(I,J+1)=YS(I,J)+RL(J)*DYS(I,J)+BN(J)*BMYS(I,KST)+DN(J)*VYS(I,J+1
     1)
  422 CONTINUE
      IF(NDIAG) 423,424,423
C                      DIAGNOSTIC 2
  423 WRITE (6,136)
      WRITE (6,118)IST,IFN,JST,JFN,KST,KFN,KMD,NCC
      WRITE (6,144)((DXC(I,J),DXS(I,J),DYC(I,J),DYS(I,J),     XC(I,J),XS(
     1I,J),YC(I,J),YS(I,J),I=1,10),J=1,NS)
      WRITE (6,145)(DIA(J),DIB(J),DIC(J),DID(J),DVUX(J),      DVUY(J),J=1
     1,NS)
      KST=NS+1
      WRITE (6,104)((VXC(I,J),VXS(I,J),VYC(I,J),VYS(I,J),      I=1,10),J=1
     1,KST)
      KST=NS+NS
      WRITE (6,104)((BMXC(I,J),BMXS(I,J),BMYC(I,J),BMYS(I,J),I=1,10),J=1
     1,KST)
  424 IF(NS-JFN) 446,446,425
C     ROTOR HAS COUPLING STATIONS
  425 KST=JFN+JFN
      IF(IST-10) 426,438,438
  426 DO 427 J=1,4
      F(1,J,NCC)=BMXC(J,KST)
      F(2,J,NCC)=BMXS(J,KST)
      F(3,J,NCC)=BMYC(J,KST)
      F(4,J,NCC)=BMYS(J,KST)
      KFN=J+4
      B(1,J)=-BMXC(KFN,KST)
      B(2,J)=-BMXS(KFN,KST)
      B(3,J)=-BMYC(KFN,KST)
      B(4,J)=-BMYS(KFN,KST)
      DO 427 I=1,4
      A(I,J)=F(I,J,NCC)
  427 C(I,J)=F(I,J,NCC)
      CF9=SCF
      MAT=1
      IF(NDIAG) 429,430,429
C                      DIAGNOSTIC 3
  429 WRITE (6,137)
      WRITE (6,104)((C(I,J),I=1,4),J=1,4),((B(I,J),I=1,4),J=1,4),((A(I,J
     1),I=1,4),J=1,4),((F(I,J,NCC),I=1,4),J=1,4)
  430 KFN=KFN
      CALL EQS
      GO TO (431,510,511),KFN
  431 D(1,1)=-BMXC(9,KST)
```

```
     D(2,1)=-BMXS(9,KST)
     D(3,1)=-BMYC(9,KST)
     D(4,1)=-BMYS(9,KST)
     CF9=SCF
     MAT=2
     KFN=KFN
     CALL EOS
     GO TO (432,510,511),KFN
 432 DO 433 I=1,4
 433 A(I,5)=C(I,1)
     DO 434 J=JST,JFN
     DO 434 K=1,5
     KST=K+4
     DO 434 I=1,4
     VXC(KST,J+1)=VXC(KST,J+1)+VXC(I,J+1)*A(I,K)
     VXS(KST,J+1)=VXS(KST,J+1)+VXS(I,J+1)*A(I,K)
     VYC(KST,J+1)=VYC(KST,J+1)+VYC(I,J+1)*A(I,K)
     VYS(KST,J+1)=VYS(KST,J+1)+VYS(I,J+1)*A(I,K)
     XC(KST,J)=XC(KST,J)+XC(I,J)*A(I,K)
     XS(KST,J)=XS(KST,J)+XS(I,J)*A(I,K)
     YC(KST,J)=YC(KST,J)+YC(I,J)*A(I,K)
     YS(KST,J)=YS(KST,J)+YS(I,J)*A(I,K)
     DXC(KST,J)=DXC(KST,J)+DXC(I,J)*A(I,K)
     DXS(KST,J)=DXS(KST,J)+DXS(I,J)*A(I,K)
     DYC(KST,J)=DYC(KST,J)+DYC(I,J)*A(I,K)
 434 DYS(KST,J)=DYS(KST,J)+DYS(I,J)*A(I,K)
     KFN=JFN+JFN
     KMD=JST+JST
     DO 436 J=KMD,KFN
     DO 436 K=1,5
     KST=K+4
     DO 436 I=1,4
     BMXC(KST,J)=BMXC(KST,J)+BMXC(I,J)*A(I,K)
     BMXS(KST,J)=BMXS(KST,J)+BMXS(I,J)*A(I,K)
     BMYC(KST,J)=BMYC(KST,J)+BMYC(I,J)*A(I,K)
 436 BMYS(KST,J)=BMYS(KST,J)+BMYS(I,J)*A(I,K)
     GO TO 442
 438 D(1,1)=-BMXC(10,KST)
     D(2,1)=-BMXS(10,KST)
     D(3,1)=-BMYC(10,KST)
     D(4,1)=-BMYS(10,KST)
     DO 428 J=1,4
     DO 428 I=1,4
 428 C(I,J)=F(I,J,NCC)
     CF9=SCF
     MAT=3
     KFN=KFN
     CALL EOS
     GO TO (439,510,511),KFN
 439 DO 440 J=JST,JFN
     DO 440 I=1,4
     VXC(10,J+1)=VXC(10,J+1)+VXC(I,J+1)*C(I,1)
     VXS(10,J+1)=VXS(10,J+1)+VXS(I,J+1)*C(I,1)
     VYC(10,J+1)=VYC(10,J+1)+VYC(I,J+1)*C(I,1)
     VYS(10,J+1)=VYS(10,J+1)+VYS(I,J+1)*C(I,1)
     XC(10,J)=XC(10,J)+XC(I,J)*C(I,1)
     XS(10,J)=XS(10,J)+XS(I,J)*C(I,1)
     YC(10,J)=YC(10,J)+YC(I,J)*C(I,1)
     YS(10,J)=YS(10,J)+YS(I,J)*C(I,1)
     DXC(10,J)=DXC(10,J)+DXC(I,J)*C(I,1)
     DXS(10,J)=DXS(10,J)+DXS(I,J)*C(I,1)
     DYC(10,J)=DYC(10,J)+DYC(I,J)*C(I,1)
 440 DYS(10,J)=DYS(10,J)+DYS(I,J)*C(I,1)
```

```
      KFN=JFN+JFN
      KMD=JST+JST
      DO 441 J=KMD,KFN
      DO 441 I=1,4
      BMXC(10,J)=BMXC(10,J)+BMXC(I,J)*C(I,1)
      BMXS(10,J)=BMXS(10,J)+BMXS(I,J)*C(I,1)
      BMYC(10,J)=BMYC(10,J)+BMYC(I,J)*C(I,1)
  441 BMYS(10,J)=BMYS(10,J)+BMYS(I,J)*C(I,1)
  442 JST=JFN
      NCC=NCC+1
      IF(NCC-NC) 444,444,443
  443 JFN=NS
      GO TO 445
  444 JFN=LC(NCC)
  445 GO TO 404
C                        END CONDITIONS
  446 KST=NS+NS
      KFN=NS+1
      DO 447 J=1,8
      CFM(1,J)=BMXC(J,KST)
      CFM(2,J)=BMXS(J,KST)
      CFM(3,J)=BMYC(J,KST)
      CFM(4,J)=BMYS(J,KST)
      CFM(5,J)=VXC(J,KFN)
      CFM(6,J)=VXS(J,KFN)
      CFM(7,J)=VYC(J,KFN)
  447 CFM(8,J)=VYS(J,KFN)
      RHS(1,1)=-BMXC(9,KST)
      RHS(2,1)=-BMXS(9,KST)
      RHS(3,1)=-BMYC(9,KST)
      RHS(4,1)=-BMYS(9,KST)
      RHS(5,1)=-VXC(9,KFN)
      RHS(6,1)=-VXS(9,KFN)
      RHS(7,1)=-VYC(9,KFN)
      RHS(8,1)=-VYS(9,KFN)
      IF(IST-10) 449,448,448
  448 RHS(1,1)=RHS(1,1)-BMXC(10,KST)
      RHS(2,1)=RHS(2,1)-BMXS(10,KST)
      RHS(3,1)=RHS(3,1)-BMYC(10,KST)
      RHS(4,1)=RHS(4,1)-BMYS(10,KST)
      RHS(5,1)=RHS(5,1)-VXC(10,KFN)
      RHS(6,1)=RHS(6,1)-VXS(10,KFN)
      RHS(7,1)=RHS(7,1)-VYC(10,KFN)
      RHS(8,1)=RHS(8,1)-VYS(10,KFN)
  449 CF9=SCF
      MAT=4
      IF(NDIAG) 450,451,450
C                        DIAGNOSTIC 4
  450 WRITE (6,138)
      WRITE (6,104)((C(I,J),I=1,4),J=1,4),((A(I,J),I=1,4),J=1,5)((CFM(I,
     1J),I=1,8),J=1,8),(RHS(I,1),I=1,8),CF9
      WRITE (6,144)((DXC(I,J),DXS(I,J),DYC(I,J),DYS(I,J),     XC(I,J),XS(
     1I,J),YC(I,J),YS(I,J),I=1,10),J=1,NS)
  451 KFN=KFN
      CALL EQS
      GO TO (452,510,511),KFN
  452 ENT(9)=1.0
      IF (NDIAG) 496,497,496
C                        DIAGNOSTIC 5
  496 WRITE (6,139)
      WRITE (6,144)((CFM(I,J),I=1,8),J=1,8)
  497 IF(IST-10) 453,500,500
  453 IF(NCAL-1) 474,473,474
```

```
473 WRITE (6,146) TOCAL
474 ENT(10)=0.0
    IF(NSYR) 454,455,454
454 WRITE (6,147)
    KMD=2
    GO TO 456
455 KMD=1
C   WRITE OUTPUT
456 WRITE (6,151)
    WRITE (6,150)
    DO 457 I=1,8
457 ENT(I)=CFM(I,1)
    IF(NC) 458,460,458
458 KFN=LC(NC)+1
    DO 459 I=1,4
459 ENT(I)=0.0
    GO TO 461
460 KFN=NS+1
461 DO 715 J=1,NU
    MNB=LU(J)
    DVUX(MNB)=UX(J)*ANSP2
715 DVUY(MNB)=UY(J)*ANSP2
    DISS=0.0
    ENGY=0.0
    MNB=1
    MBR=1
    LBRG=LB(1)
    LNBL=LU(1)
    DO 470 J=1,NS
    IF(J-KFN) 464,462,464
462 DO 463 I=1,4
463 ENT(I)=CFM(I,1)
464 KST=J+J
    KC=KST-1
    DO 465 K=1,3
    DO 465 I=1,4
465 B(I,K)=0.0
    DO 466 I=1,IFN
    B(1,1)=B(1,1)+XC(I,J)*ENT(I)
    B(2,1)=B(2,1)+XS(I,J)*ENT(I)
    B(3,1)=B(3,1)+YC(I,J)*ENT(I)
    B(4,1)=B(4,1)+YS(I,J)*ENT(I)
    B(1,2)=B(1,2)+BMXC(I,KC)*ENT(I)
    B(2,2)=B(2,2)+BMXS(I,KC)*ENT(I)
    B(3,2)=B(3,2)+BMYC(I,KC)*ENT(I)
    B(4,2)=B(4,2)+BMYS(I,KC)*ENT(I)
    B(1,3)=B(1,3)+BMXC(I,KST)*ENT(I)
    B(2,3)=B(2,3)+BMXS(I,KST)*ENT(I)
    B(3,3)=B(3,3)+BMYC(I,KST)*ENT(I)
466 B(4,3)=B(4,3)+BMYS(I,KST)*ENT(I)
    IF(J-LBRG) 709,703,709
C   TRANSMITTED FORCE, PEDESTAL MOTION
703 CF1A=RM(J)*ANSP2
    SHA(1)=CF1A*B(1,1)+DVUX(J)
    SHB(1)=CF1A*B(2,1)-DVUY(J)
    SHC(1)=CF1A*B(3,1)+DVUY(J)
    SHD(1)=CF1A*B(4,1)+DVUX(J)
    DO 704 I=1,IFN
    SHA(1)=SHA(1)+(VXC(I,J)-VXC(I,J+1))*ENT(I)
    SHB(1)=SHB(1)+(VXS(I,J)-VXS(I,J+1))*ENT(I)
    SHC(1)=SHC(1)+(VYC(I,J)-VYC(I,J+1))*ENT(I)
704 SHD(1)=SHD(1)+(VYS(I,J)-VYS(I,J+1))*ENT(I)
    IF (NPST) 705,706,705
```

```
705 CF1K=PYX(MBR)/386.069*ANSP2/AMS
    CF1M=PYY(MBR)/386.069*ANSP2/AMS
    CF1A=PCX(MBR)/AMS-CF1K
    CF1B=PCY(MBR)/AMS-CF1M
    CF1C=PCX(MBR)/AMS*ANSP
    CF1D=PCY(MBR)/AMS*ANSP
    CF1E=CF1A*CF1A+CF1C*CF1C
    SHA(3)=(SHA(1)*CF1A-SHB(1)*CF1C)/CF1E
    SHB(3)=(SHA(1)*CF1C+SHB(1)*CF1A)/CF1E
    CF1E=CF1B*CF1B+CF1D*CF1D
    SHC(3)=(SHC(1)*CF1B-SHD(1)*CF1D)/CF1E
    SHD(3)=(SHC(1)*CF1D+SHD(1)*CF1B)/CF1E
    SHA(2)=SHA(1)+CF1K*SHA(3)
    SHB(2)=SHB(1)+CF1K*SHB(3)
    SHC(2)=SHC(1)+CF1M*SHC(3)
    SHD(2)=SHD(1)+CF1M*SHD(3)
    CF1A=B(1,1)-SHA(3)
    CF1B=B(2,1)-SHB(3)
    CF1K=B(3,1)-SHC(3)
    CF1M=B(4,1)-SHD(3)
    GO TO 707
706 CF1A=B(1,1)
    CF1B=B(2,1)
    CF1K=B(3,1)
    CF1M=B(4,1)
    SHA(2)=SHA(1)
    SHB(2)=SHB(1)
    SHC(2)=SHC(1)
    SHD(2)=SHD(1)
    SHA(3)=0.0
    SHB(3)=0.0
    SHC(3)=0.0
    SHD(3)=0.0
    CF1C=0.0
    CF1D=0.0
707 CF2A=BCXX(1,MBR)+BCXX(2,MBR)*ANSP+BCXX(3,MBR)*ANSP2
    CF2B=BCXY(1,MBR)+BCXY(2,MBR)*ANSP+BCXY(3,MBR)*ANSP2
    CF2C=BCYX(1,MBR)+BCYX(2,MBR)*ANSP+BCYX(3,MBR)*ANSP2
    CF2D=BCYY(1,MBR)+BCYY(2,MBR)*ANSP+BCYY(3,MBR)*ANSP2
    CF2M=BKXY(1,MBR)+BKXY(2,MBR)*ANSP+BKXY(3,MBR)*ANSP2
    CF2N=BKYX(1,MBR)+BKYX(2,MBR)*ANSP+BKYX(3,MBR)*ANSP2
    DISS=DISS+3.1415927*(CF2A*(CF1A*CF1A+CF1B*CF1B)+CF2D*(CF1K*CF1K+
   1CF1M*CF1M)+(CF2B+CF2C)*(CF1A*CF1K+CF1B*CF1M)+(CF2M-CF2N)*(CF1B*
   2CF1K-CF1A*CF1M)+CF1C*(SHA(3)*SHA(3)+SHB(3)*SHB(3))+CF1D*(SHC(3)*
   3SHC(3)+SHD(3)*SHD(3)))
    IF (NMOM) 717,716,717
717 CF1A=0.0
    CF1B=0.0
    CF1K=0.0
    CF1M=0.0
    DO 740 I=1,IFN
    CF1A=CF1A+DXC(I,J)*ENT(I)
    CF1B=CF1B+DXS(I,J)*ENT(I)
    CF1K=CF1K+DYC(I,J)*ENT(I)
740 CF1M=CF1M+DYS(I,J)*ENT(I)
    CF2A=B(1,3)-B(1,2)-DIA(J)
    CF2B=B(2,3)-B(2,2)-DIB(J)
    CF2C=B(3,3)-B(3,2)-DIC(J)
    CF2D=B(4,3)-B(4,2)-DID(J)
    IF (NPST) 741,742,741
741 CF2M=(PSMX(MBR)-PIX(MBR)/386.069*ANSP2)/AMS
    CF2N=(PSMY(MBR)-PIY(MBR)/386.069*ANSP2)/AMS
    CF1C=PDMX(MBR)/AMS*ANSP
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      CF1 =PDMY(MBR)/AMS*ANSP
      CF1E=CF2M*CF2M+CF1C*CF1C
      CF3A=(CF2A*CF2M-CF2B*CF1C)/CF1E
      CF3B=(CF2A*CF1C+CF2B*CF2M)/CF1E
      CF1E=CF2N*CF2N+CF1D*CF1D
      CF3C=(CF2C*CF2N-CF2D*CF1D)/CF1E
      CF3D=(CF2C*CF1D+CF2D*CF2N)/CF1E
      CF1A=CF1A-CF3A
      CF1B=CF1B-CF3B
      CF1K=CF1K-CF3C
      CF1M=CF1M-CF3D
      CF2M=CF1C*(CF3A*CF3A+CF3B*CF3B)+CF1D*(CF3C*CF3C+CF3D*CF3D)
      GO TO 743
  742 CF2M=0.0
  743 DISS=DISS+3.1415927*(CF2A*CF1B-CF2B*CF1A+CF2C*CF1M-CF2D*CF1K+CF2M)
  716 DO 708 I=1,3
      CF1A=SHA(I)
      CF1B=-SHB(I)
      CF1C=SHC(I)
      CF1D=SHD(I)
      AUX(MBR,1,I)=SQRT(CF1A*CF1A+CF1B*CF1B)
      AUX(MBR,2,I)=ANG(CF1A,CF1B)
      AUX(MBR,3,I)=SQRT(CF1C*CF1C+CF1D*CF1D)
      AUX(MBR,4,I)=ANG(CF1D,CF1C)
      CF2A=CF1A*CF1A
      CF2B=CF1B*CF1B
      CF2C=CF1C*CF1C
      CF2D=CF1D*CF1D
      CF1E=(CF2A+CF2B+CF2C+CF2D)/2.0
      CF1K=(CF2A+CF2B-CF2C-CF2D)/2.0
      CF1M=CF1A*CF1C-CF1B*CF1D
      CF1N=CF1A*CF1B-CF1C*CF1D
      CF2A=(CF2A-CF2B+CF2C-CF2D)/2.0
      CF2B=SQRT(CF1K*CF1K+CF1M*CF1M)
      CF3B=CF1A*CF1D+CF1B*CF1C
      CF3B=CF3B/ABS(CF3B)
      BUX(MBR,1,I)=SQRT(CF1E+CF2B)
      BUX(MBR,2,I)=CF3B*SQRT(CF1E-CF2B)
      BUX(MBR,3,I)=ANG(CF1K,CF1M)/2.0
  708 BUX(MBR,4,I)=ANG(CF2A,CF1N)/2.0
      IF(MBR-NB) 702,701,701
  701 LBRG=NS+2
      GO TO 709
  702 MBR=MBR+1
      LBRG=LB(MBR)
  709 IF (J-LNBL) 714,710,714
  710 IF (MNB-NU) 712,711,711
  711 LNBL=NS+2
      GO TO 713
  712 MNB=MNB+1
      LNBL=LU(MNB)
  713 ENGY=ENGY+3.1415927*(DVUX(J)*(B(2,1)-B(3,1))+DVUY(J)*(B(1,1)+
     1B(4,1)))
C     CONVERT RESULTS TO ELLIPSIS
  714 DO 469 I=1,3
      CF1A=B(1,I)*B(1,I)
      CF1B=B(2,I)*B(2,I)
      CF1C=B(3,I)*B(3,I)
      CF1D=B(4,I)*B(4,I)
      CF1E=(CF1A+CF1B+CF1C+CF1D)/2.0
      CF1K=(CF1A+CF1B-CF1C-CF1D)/2.0
      CF1M=B(1,I)*B(3,I)+B(2,I)*B(4,I)
      CF1N=(CF1A-CF1B+CF1C-CF1D)/2.0
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      CF1B=-B(1,I)*B(2,I)-B(3,I)*B(4,I)
      CF1C=SQRT(CF1K*CF1K+CF1M*CF1M)
      CF3H=B(1,I)*B(4,I)-B(2,I)*B(3,I)
      CF3J=CF3H/ABS(CF3H)
      B(1,I)=SQRT(CF1E+CF1C)
      B(2,I)=CF3J*SQRT(CF1E-CF1C)
  467 B(3,I)=ANG(CF1K,CF1M)/2.0
  468 B(4,I)=ANG(CF1A,CF1B)/2.0
  469 CONTINUE
      WRITE (6,148)J,B(1,1),B(2,1),B(3,1),B(4,1),B(1,2),     B(2,2),B(3,
     12),B(4,2)
  470 WRITE (6,149)B(1,3),B(2,3),B(3,3),B(4,3)
      CF1A=AMS*AMS
      DISS=DISS/CF1A
      ENGY=ENGY/AMS
      WRITE (6,730)
      DO 725 I=1,3
      IF (I-2) 723,720,722
  720 IF (NPST) 721,726,721
  721 WRITE (6,731)
      GO TO 723
  722 WRITE (6,732)
  723 WRITE (6,733)
      DO 724 J=1,NB
      MBR=LB(J)
  724 WRITE (6,148)MBR,BUX(J,1,I),BUX(J,2,I),BUX(J,3,I),    BUX(J,4,I),AU
     1X(J,1,I),AUX(J,2,I),AUX(J,3,I),AUX(J,4,I)
  725 CONTINUE
  726 WRITE (6,734)ENGY,DISS
      GO TO (513,480,513),KMD
C     MAKE READY FOR GYROSCOPIC MOMENT CALCULATION
  480 IST=10
      IFN=10
      WRITE (6,153)
C     CALCULATE GYROSCOPIC MOMENT
  481 DO 482 I=1,8
  482 ENT(I)=CFM(I,1)
      IF(NC) 483,485,483
  483 KFN=LC(NC)
      DO 484 I=1,4
  484 ENT(I)=0.0
      GO TO 486
  485 KFN=NS+1
  486 DO 493 J=1,NS
      IF(J-KFN) 489,487,489
  487 DO 488 I=1,4
  488 ENT(I)=CFM(I,1)
  489 CF1A=0.0
      CF1B=0.0
      CF1C=0.0
      CF1D=0.0
      DO 490 I=1,IFN
      CF1A=CF1A+DXC(I,J)*ENT(I)
      CF1B=CF1B+DXS(I,J)*ENT(I)
      CF1C=CF1C+DYC(I,J)*ENT(I)
  490 CF1D=CF1D+DYS(I,J)*ENT(I)
      CF1E=CF1A+CF1D
      CF1K=CF1B-CF1C
      CF1M=CF1A*CF1D-CF1B*CF1C
      CF1N=CF1E*CF1E+CF1K*CF1K
      IF(CF1N) 492,491,492
  491 DIA(J)=0.0
      DIB(J)=0.0
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      DIC(J)=0.0
      DID(J)=0.0
      GO TO 493
  492 CF1M=CF1M/CF1N
      CF1N=RIP(J)*ANSP2
      CF1E=CF1N*CF1E*CF1M
      CF1K=CF1N*CF1K*CF1M
      CF1N=RIT(J)*ANSP2
      DIA(J)=CF1E-CF1N*CF1A
      DIB(J)=CF1K-CF1N*CF1B
      DIC(J)=-CF1K-CF1N*CF1C
      DID(J)=CF1E-CF1N*CF1D
  493 CONTINUE
      IF(NDIAG) 494,495,494
C                  DIAGNOSTIC 6
  494 WRITE (6,140)
      WRITE (6,104)(DIA(J),DIB(J),DIC(J),DID(J),J=1,NS),      CF1A,CF1B,C
     1F1C,CF1D,CF1E,CF1K,CF1M,CF1N,CF1,CF2,CF3,CF4,           CF5,CF6,CF7
     2,CF8,(CFM(I,1),ENT(I),I=1,8)
  495 GO TO 401
C                  GYROSCOPIC MOMENT ITERATION
  500 CF2A=ABS(CFM(1,1)-CF1)+ABS(CFM(2,1)-CF2)+ABS(CFM(3,1)-CF3)+    ABS
     1(CFM(4,1)-CF4)+ABS(CFM(5,1)-CF5)+ABS(CFM(6,1)-CF6)+         ABS(CF
     2M(7,1)-CF7)+ABS(CFM(8,1)-CF8)
      CF2B=0.0
      DO 501 I=1,8
  501 CF2B=CF2B+ABS(CFM(I,1))
      IF(CF2B) 502,503,502
  502 CF2A=CF2A/CF2B
  503 WRITE (6,152)NITC,CF2A
      IF(CF2A-DGYR) 506,506,504
  504 NITC=NITC+1
      IF(NITC-NIT) 505,505,506
  505 CF1=CFM(1,1)
      CF2=CFM(2,1)
      CF3=CFM(3,1)
      CF4=CFM(4,1)
      CF5=CFM(5,1)
      CF6=CFM(6,1)
      CF7=CFM(7,1)
      CF8=CFM(8,1)
      GO TO 481
  506 WRITE (6,154)
      KMD=3
      ENT(10)=1.0
      GO TO 456
C                  ADVANCE SPEED
  513 IF(NCAL-1) 512,507,512
  512 JCAL=JCAL+1
      IF(NCAL-JCAL) 508,901,901
  901 III=2
      GO TO 200
  507 SPCAL=SPCAL+SPINC
      ANSP=0.10471976*SPCAL
      IF(SPEN-SPCAL) 508,902,902
  902 III=3
      GO TO 200
  508 IF(INPUT) 509,201,509
C                  PROGRAM END
  509 WRITE (6,999)
  999 FORMAT (1H1,17HLAST SET OF INPUT)
      STOP
C                  XSIMCOF DIAGNOSTIC
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510 WRITE (6,155)MAT
    GO TO 513
511 WRITE (6,156)MAT
    GO TO 513
100 FORMAT(72H0
   1                    )
101 FORMAT(72H
   1                    )
102 FORMAT(120H1                                    UNBALANCE RESPONSE OF ROTOR WIT
   1H NON-UNIFORM BEARING SUPPORTS     PN0011                                    )
103 FORMAT(120H                                                                   
   1A. TECHNOLOGY,INC.                                                  MECHANIC)
104 FORMAT(1P4E15.7)
105 FORMAT(10I5)
106 FORMAT(I5,1PE23.6)
107 FORMAT(30H0YOUNGS MODULUS   SCALE FACTOR)
108 FORMAT(120H0 STATIONS     NO.BRGS.    NO.UNBAL.    NO.COUPL.    PED.F
   1LEX.    BRG.MOMENT  GYRO.MOM.    NO.CASES     DIAGNOSTIC      INPUT    )
109 FORMAT(1P5E15.7)
110 FORMAT(I7,9I12)
111 FORMAT(36H0                              ROTOR DATA )
112 FORMAT(1P3E14.6)
113 FORMAT(1P5E14.6)
114 FORMAT(I7,1P3E20.7)
115 FORMAT(I7,1P5E20.7)
116 FORMAT(72H STATION NO.      MASS                LENGTH          CROSS
   1 SECT.INERTIA   )
117 FORMAT(120H STATION NO.      MASS                LENGTH          CROS
   1S SECT.INERTIA  POLAR MOM.INERTIA  TRANSV.MOM.INERTIA              )
118 FORMAT(14I5)
119 FORMAT(36H0ITERAT.   ITERAT.CONVERG.LIMIT       )
120 FORMAT(18H0BEARING STATIONS )
121 FORMAT(71H0                                                       BEARING
   1AT STATION NO. I2)
122 FORMAT(120H         KXX                 CXX                KXY              CXY
   1         KYY                 CYY                KYX              CYX      )
123 FORMAT(1P8E15.6)
124 FORMAT(120H         MXX                 DXX                MXY              DXY
   1         MYY                 DYY                MYX              DYX      )
125 FORMAT(1P6E12.4)
126 FORMAT(I7,1P6E16.4)
127 FORMAT(102H BRG.STATION  MASS.X-DIR.          KX                CX
   1        MASS.Y-DIR.         KY                CY    )
128 FORMAT(78H0                                                    PEDESTAL DATA.
   1TRANSLATORY MOTION     )
129 FORMAT(78H0                                                    PEDESTAL DATA.
   1ROTATIONAL MOTION      )
130 FORMAT(102H BRG.STATION  INERTIA.X            MX                DX
   1        INERTIA.Y           MY                DY    )
131 FORMAT(I5,1P2E15.7)
132 FORMAT(I7,1P2E21.7)
133 FORMAT(54H0UNBALANCE ST.  X-UNBALANCE           Y-UNBALANCE        )
134 FORMAT(18H0COUPLING STATIONS)
135 FORMAT(18H0DIAGNOSTIC 1      )
136 FORMAT(18H0DIAGNOSTIC 2      )
137 FORMAT(18H0DIAGNOSTIC 3      )
138 FORMAT(18H0DIAGNOSTIC 4      )
139 FORMAT(18H0DIAGNOSTIC 5      )
140 FORMAT(18H0DIAGNOSTIC 6      )
141 FORMAT(42H0INITIAL SPEED  FINAL SPEED    SPEED INCR.)
144 FORMAT(1P8E15.7)
145 FORMAT(1P6E15.7)
146 FORMAT(13H0ROTOR SPEED=,1PE14.7,3HRPM)
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147 FORMAT(30H WITHOUT GYROSCOPIC MOMENT      )
148 FORMAT(I4,1PE15.5,1P3E14.5,1PE17.5,1P3E14.5)
149 FORMAT(1PE78.5,1P3E14.5)
150 FORMAT(120H STATION MAJOR AXIS    MINOR AXIS    ANGLE X-MAJOR  PHASE
   1 ANGLE        MAJOR AXIS     MINOR AXIS   ANGLE X-MAJOR  PHASE ANGLE)
151 FORMAT(32H                                     AMPLITUDE
   1                               BENDING MOMENT)
152 FORMAT(I7,1PE17.7)
153 FORMAT(24H0ITERAT.NO.      ERROR      )
154 FORMAT(24H WITH GYROSCOPIC MOMENT )
155 FORMAT(30H0OVER/UNDERFLOW IN XSIMEQF AT I1)
156 FORMAT(34H0MATRIX IS SINGULAR IN XSIMEQF AT I1)
157 FORMAT(1P4E14.6)
730 FORMAT(38H0 FORCE TRANSMITTED TO BEARING HOUSING)
731 FORMAT(33H0 FORCE TRANSMITTED TO FOUNDATION)
732 FORMAT(18H0 PEDESTAL MOTION )
733 FORMAT(120H BRG.NO. MAJOR AXIS    MINOR AXIS    ANGLE X-MAJOR  PHASE
   1 ANGLE        X-AMPLITUDE    X-PHASE ANG    Y-AMPLITUDE    Y-PHASE ANG)
734 FORMAT(15H0 ENERGY INPUT=,1PE14.7,21H    ENERGY DISSIPATED=,1PE14.7
   1)
    END
$IBFTC SUBRS    M94,XR7,LIST,NODECK
      SUBROUTINE SUBR
      DIMENSION BMXC(10, 80),BMXS(10, 80),BMYC(10, 80),BMYS(10, 80),VXC
     1(10,41),VXS(10,41),VYC(10,41),VYS(10,41),DXC(10,40),DXS(10,40),DYC
     2(10,40),DYS(10,40),XC(10,40),XS(10,40),YC(10,40),YS(10,40),DMXA(40
     3),DMXB(40),DMXC(40),DMXD(40),DMYA(40),DMYB(40),DMYC(40),DMYD(40),
     4DVXA(40),DVXB(40),DVXC(40),DVXD(40),DVYA(40),DVYB(40),DVYC(40),
     5DVYD(40),RM(40),RL(40),RS(40),RIP(40),RIT(40),DIA(40),DIB(40),DIC(
     640),DID(40),AN(40),BN(40),DN(40),UX(40),UY(40),LU(40),LB(25),BKXX(
     73,25),BCXX(3,25),BKXY(3,25),BCXY(3,25),BKYY(3,25),BCYY(3,25),BKYX(
     83,25),BCYX(3,25),BSMXX(3,25),BDMXX(3,25),BSMXY(3,25),BDMXY(3,25),
     9BSMYY(3,25),BDMYY(3,25),BSMYX(3,25),BDMYX(3,25)
      DIMENSION PMX(25),PMY(25),PKX(25),PCX(25),PKY(25),PCY(25),PIX(25),
     1PIY(25),PSMX(25),PDMX(25),PSMY(25),PDMY(25),LC(20),A(8,8),B(8,4),
     2C(8,4),D(8,1),F(4,4,20),CFM(8,8),ENT(10),RHS(8,1),DVUX(80),
     3 DVUY(80),DUMMY(300),SHA(3),SHB(3),SHC(3),SHD(3),AUX(25,4,3),
     4BUX(25,4,3),DUM1(100),CLNR(8)
      COMMON  A       , B       , C       , D       , CFM     , ENT
      COMMON  RHS     , DUM1    , CF9     , MAT     , KFN     , CLNR
      COMMON  PRN3
      COMMON NS,NB,NJ,NC,NPST,NMOM,NGYR,NCAL,NDIAG,INPUT,YM,SCF,RM,RL,
     1RS,NIT,DGYR,RIP,RIT,LB,LU,UX,UY,LC,PMX,PKX,PCX,PMY,PKY,PCY,KST,
     2PIX,PSMX,PDMX,PIY,PSMY,PDMY,SPST,SPFN,SPINC,BKXX,BCXX,BKXY,BCXY,
     3BKYY,BCYY,BKYX,BCYX,BSMXX,BDMXX,BSMXY,BDMXY,BSMYY,BDMYY,BSMYX,
     4BDMYX,CF1K,CF1C,CF1D,CF1E,CF2K,CF2C,CF2D,CF2E,CF2A,CF2B,CF2M,CF2N,
     5CF1A,CF1B,CF1M,CF1N,CF1,CF2,CF3,CF4,CF5,CF6,CF7,CF8,STF,ANSP2,
     6ANSP,SPCAL,DVXA,DVXB,DVXC,DVXD,DVYA,DVYB,DVYC,DVYD,DMXA,DMXB,DMXC,
     7DMXD,DMYA,DMYB,DMYC,DMYD,AN,BN,DN,III
      COMMON BMXC,BMXS,BMYC,BMYS,VXC,VXS,VYC,VYS,DXC,DXS,DYC,DYS,XC,XS,
     1YC,YS,DIA,DIB,DIC,DID,DVUX,DVUY,DUMMY,SHA,SHB,SHC,SHD,AUX,BUX
      COMMON JCAL,AMS,NITC
100 FORMAT(72H0
   1                  )
101 FORMAT(72H
   1                  )
102 FORMAT(120H1                              UNBALANCE RESPONSE OF ROTOR WIT
   1H NON-UNIFORM BEARING SUPPORTS     PN0011                          )
103 FORMAT(120H                                                   MECHANIC
   1AL TECHNOLOGY,INC.                                              )
104 FORMAT(1P4E15.7)
105 FORMAT(10I5)
106 FORMAT(I5,1PE23.6)
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  107 FORMAT(30H0YOUNGS MODULUS    SCALE FACTOR)
  108 FORMAT(120H0 STATIONS     NO.BRGS.    NO.UNBAL.    NO.COUPL.    PED.F
     1LEX.    BRG.MOMENT  GYRO.MOM.    NO.CASES     DIAGNOSTIC     INPUT    )
  109 FORMAT(1P5E15.7)
  110 FORMAT(I7,9I12)
  111 FORMAT(36H0                        ROTOR DATA )
  112 FORMAT(1P3E14.6)
  113 FORMAT(1P5E14.6)
  114 FORMAT(I7,1P3E20.7)
  115 FORMAT(I7,1P5F20.7)
  116 FORMAT(72H STATION NO.       MASS                   LENGTH        CROSS
     1 SECT.INERTIA    )
  117 FORMAT(120H STATION NO.       MASS                   LENGTH        CROS
     1S SECT.INERTIA   POLAR MOM.INERTIA   TRANSV.MOM.INERTIA              )
  118 FORMAT(14I5)
  119 FORMAT(36H0ITERAT.    ITERAT.CONVERG.LIMIT      )
  120 FORMAT(18H0BEARING STATIONS )
  121 FORMAT(71H0                                                 BEARING
     1AT STATION NO. I2)
  122 FORMAT(120H        KXX                 CXX             KXY           CXY
     1               KYY              CYY            KYX             CYX     )
  123 FORMAT(1P8E15.6)
  124 FORMAT(120H        MXX                 DXX             MXY           DXY
     1               MYY              DYY            MYX             DYX     )
  125 FORMAT(1P6E12.4)
  126 FORMAT(I7,1P6F16.4)
  127 FORMAT(102H BRG.STATION  MASS.X-DIR.        KX              CX
     1       MASS.Y-DIR.          KY              CY    )
  128 FORMAT(78H0                                              PEDESTAL DATA.
     1TRANSLATORY MOTION     )
  129 FORMAT(78H0                                              PEDESTAL DATA.
     1ROTATIONAL MOTION      )
  130 FORMAT(102H BRG.STATION  INERTIA.X          MX              DX
     1        INERTIA.Y           MY              DY    )
  131 FORMAT(I5,1P2F15.7)
  132 FORMAT(I7,1P2F21.7)
  133 FORMAT(54H0UNBALANCE ST.  X-UNBALANCE           Y-UNBALANCE       )
  134 FORMAT(18H0COUPLING STATIONS)
  135 FORMAT(18H0DIAGNOSTIC 1      )
  141 FORMAT(42H0INITIAL SPEED  FINAL SPEED    SPEED INCR.)
  144 FORMAT(1P8E15.7)
  145 FORMAT(1P6E15.7)
  146 FORMAT(13H0ROTOR SPEED=,1PE14.7,3HRPM)
  156 FORMAT(34H0MATRIX IS SINGULAR IN XSIMEQF AT I1)
 157  FORMAT (1P4E14.6)
      GO TO (900,227,300),III
  900 READ  (5,100)
      READ  (5,101)
      READ  (5,105)NS,NB,NU,NC,NPST,NMOM,NGYR,NCAL,NDIAG,INPUT
      READ  (5,104)YM,SCF
      WRITE (6,102)
      WRITE (6,103)
      WRITE (6,100)
      WRITE (6,101)
      WRITE (6,108)
      WRITE (6,110)NS,NB,NU,NC,NPST,NMOM,NGYR,NCAL,NDIAG,INPUT
      WRITE (6,107)
      WRITE (6,104)YM,SCF
      IF(NGYR) 202,201,202
  201 READ  (5,112)(RM(J),RL(J),RS(J),J=1,NS)
      WRITE (6,111)
      WRITE (6,116)
      WRITE (6,114)(J,RM(J),RL(J),RS(J),J=1,NS)
```

```
      GO TO 203
  202 READ  (5,106)NIT,DGYR
      WRITE (6,119)
      WRITE (6,105)NIT,DGYR
      WRITE (6,111)
      READ  (5,113)(RY(J),RL(J),RS(J),RIP(J),RIT(J),J=1,NS)
      WRITE (6,117)
      WRITE (6,115)(J,RM(J),RL(J),RS(J),RIP(J),RIT(J),J=1,NS)
  203 READ  (5,118)(LB(J),J=1,NB)
      WRITE (6,120)
      WRITE (6,118)(LB(J),J=1,NB)
  212 READ  (5,131)(LU(J),UX(J),UY(J),J=1,NU)
      WRITE (6,133)
      WRITE (6,132)(LU(J),UX(J),UY(J),J=1,NU)
  214 IF(NC) 215,207,215
  215 READ  (5,118)(LC(J),J=1,NC)
      WRITE (6,134)
      WRITE (6,118)(LC(J),J=1,NC)
  207 IF(NPST) 208,228,208
  208 WRITE (6,128)
      WRITE (6,127)
      DO 209 J=1,NB
      READ  (5,125)PMX(J),PKX(J),PCX(J),PMY(J),PKY(J),PCY(J)
      KST=LB(J)
  209 WRITE (6,126)KST,PMX(J),PKX(J),PCX(J),PMY(J),PKY(J),    PCY(J)
      IF(NMOM) 210,228,210
  210 WRITE (6,129)
      WRITE (6,130)
      DO 211 J=1,NB
      READ  (5,125)PIX(J),PSMX(J),PDMX(J),PIY(J),PSMY(J),       PDMY(J)
      KST=LB(J)
  211 WRITE (6,126)KST,PIX(J),PSMX(J),PDMX(J),PIY(J),PSMY(J),PDMY(J)
  228 IF(NCAL-1) 221,220,221
  220 READ  (5,112)SPST,SPFN,SPINC
      WRITE (6,141)
      WRITE (6,112)SPST,SPFN,SPINC
      READ  (5,112)((BKXX(I,J),I=1,3),(BCXX(I,J),I=1,3),        (BKXY(I,J
     1),I=1,3),(BCXY(I,J),I=1,3),(BKYY(I,J),I=1,3),(BCYY(I,J), I=1,3),(B
     2KYX(I,J),I=1,3),(BCYX(I,J),I=1,3),J=1,NB)
      DO 204 J=1,NB
      KST=LB(J)
      WRITE (6,121)KST
      WRITE (6,122)
  204 WRITE (6,123)(BKXX(I,J),BCXX(I,J),BKXY(I,J),BCXY(I,J), BKYY(I,J),B
     1CYY(I,J),BKYX(I,J),BCYX(I,J),I=1,3)
      IF(NMOM) 205,216,205
  205 READ (5,112)((BSMXX(I,J),I=1,3),(BDMXX(I,J),I=1,3),(BSMXY(I,
     1J),I=1,3),(BDMXY(I,J),I=1,3),(BSMYY(I,J),I=1,3),(BDMYY(I,J),I=1
     2,3),(BSMYX(I,J),I=1,3),(BDMYX(I,J),I=1,3),J=1,NB)
      DO 206 J=1,NB
      KST=LB(J)
      WRITE (6,121)KST
      WRITE (6,124)
  206 WRITE (6,123)(BSMXX(I,J),BDMXX(I,J),BSMXY(I,J),BDMXY(I,J),BSMYY(I,
     1J),BDMYY(I,J),BSMYX(I,J),BDMYX(I,J),I=1,3)
      GO TO 216
  221 JCAL=1
  227 READ  (5,157)SPST
      READ  (5,157)(BKXX(1,J),BCXX(1,J),BKXY(1,J),BCXY(1,J),    BKYY(1,J)
     1,BCYY(1,J),BKYX(1,J),BCYX(1,J),J=1,NB)
      WRITE (6,146)SPST
      DO 223 J=1,NB
      KST=LB(J)
```

```
      WRITE (6,121)KST
      WRITE (6,122)
  223 WRITE (6,123)BKXX(1,J),BCXX(1,J),BKXY(1,J),BCXY(1,J),BKYY(1,J),BCY
     1Y(1,J),BKYX(1,J),BCYX(1,J)
      IF(NMOM) 224,216,224
  224 READ  (5,157)(BSMXX(1,J),BDMXX(1,J),BSMXY(1,J),BDMXY      (1,J),BSM
     1YY(1,J),BDMYY(1,J),BSMYX(1,J),BDMYX(1,J),J=1,NB)
      DO 226 J=1,NB
      KST=LB(J)
      WRITE (6,121)KST
      WRITE (6,124)
  225 WRITE (6,123)BSMXX(1,J),BDMXX(1,J),BSMXY(1,J),BDMXY(1,J),BSMYY(1,J
     1),BDMYY(1,J),BSMYX(1,J),BDMYX(1,J)
      DO 226 I=2,3
      BKXX(I,J)=0.0
      BCXX(I,J)=0.0
      BKXY(I,J)=0.0
      BCXY(I,J)=0.0
      BKYY(I,J)=0.0
      BCYY(I,J)=0.0
      BKYX(I,J)=0.0
      BCYX(I,J)=0.0
      BSMXX(I,J)=0.0
      BDMXX(I,J)=0.0
      BSMXY(I,J)=0.0
      BDMXY(I,J)=0.0
      BSMYY(I,J)=0.0
      BDMYY(I,J)=0.0
      BSMYX(I,J)=0.0
      BDMYX(I,J)=0.0
  226 CONTINUE
  216 GO TO 250
C                        CONVERT INPUT UNITS
  250 AMS=1000.0
      CF1=386.069*AMS
      CF2=CF1/2.0
      RS(NS)=RS(1)
      DO 251 J=1,NS
      RM(J)=RM(J)/CF1
      RIP(J)=RIP(J)/CF2
      RIT(J)=RIT(J)/CF1
      STF=YM/AMS*RS(J)
      AN(J)=RL(J)/STF
      BN(J)=RL(J)/2.0*AN(J)
  251 DN(J)=RL(J)/3.0*BN(J)
      DO 252 J=1,NU
      UX(J)=UX(J)/6177.1
  252 UY(J)=UY(J)/6177.1
      SPCAL=SPST
      ANSP=0.10471976*SPCAL
      NITC=1
C                        SPEED DEPENDENT PARAMETERS
  300 ANSP2=ANSP*ANSP
      DO 301 J=1,NS
      DMXA(J)=0.0
      DMXB(J)=0.0
      DMXC(J)=0.0
      DMXD(J)=0.0
      DMYA(J)=0.0
      DMYB(J)=0.0
      DMYC(J)=0.0
      DMYD(J)=0.0
      STF=RM(J)*ANSP2
```

```
      DVXA(J)=STF
      DVYA(J)=STF
      DVXB(J)=0.0
      DVXC(J)=0.0
      DVXD(J)=0.0
      DVYB(J)=0.0
      DVYC(J)=0.0
      DVYD(J)=0.0
      DIA(J)=0.0
      DIB(J)=0.0
      DIC(J)=0.0
  301 DID(J)=0.0
  302 DO 311 J=1,NB
      KST=LB(J)
      KFN=0
      CF1K=BKXX(1,J)+BKXX(2,J)*ANSP+BKXX(3,J)*ANSP2
      CF1C= BCXX(1,J)+BCXX(2,J)*ANSP+BCXX(3,J)*ANSP2
      CF1D=BKXY(1,J)+BKXY(2,J)*ANSP+BKXY(3,J)*ANSP2
      CF1E= BCXY(1,J)+BCXY(2,J)*ANSP+BCXY(3,J)*ANSP2
      CF2K=BKYY(1,J)+BKYY(2,J)*ANSP+BKYY(3,J)*ANSP2
      CF2C= BCYY(1,J)+BCYY(2,J)*ANSP+BCYY(3,J)*ANSP2
      CF2D=BKYX(1,J)+BKYX(2,J)*ANSP+BKYX(3,J)*ANSP2
      CF2E= BCYX(1,J)+BCYX(2,J)*ANSP+BCYX(3,J)*ANSP2
      IF(NPST) 303,304,303
  303 CF1M=PKX(J)-PMX(J)/386.069*ANSP2
      CF1N=PCX(J)*ANSP
      CF1A=CF1K+CF1M
      CF1B=CF1C+CF1N
      CF2M=PKY(J)-PMY(J)/386.069*ANSP2
      CF2N=PCY(J)*ANSP
      CF2A=CF2K+CF2M
      CF2B=CF2C+CF2N
      GO TO 307
  304 KFN=1
      CF1K=BSMXX(1,J)+BSMXX(2,J)*ANSP+BSMXX(3,J)*ANSP2
      CF1C= BDMXX(1,J)+BDMXX(2,J)*ANSP+BDMXX(3,J)*ANSP2
      CF1D=BSMXY(1,J)+BSMXY(2,J)*ANSP+BSMXY(3,J)*ANSP2
      CF1E= BDMXY(1,J)+BDMXY(2,J)*ANSP+BDMXY(3,J)*ANSP2
      CF2K=BSMYY(1,J)+BSMYY(2,J)*ANSP+BSMYY(3,J)*ANSP2
      CF2C= BDMYY(1,J)+BDMYY(2,J)*ANSP+BDMYY(3,J)*ANSP2
      CF2D=BSMYX(1,J)+BSMYX(2,J)*ANSP+BSMYX(3,J)*ANSP2
      CF2E= BDMYX(1,J)+BDMYX(2,J)*ANSP+BDMYX(3,J)*ANSP2
      IF(NPST) 305,306,305
  305 CF1M=PSMX(J)-PIX(J)/386.069*ANSP2
      CF1N=PDMX(J)*ANSP
      CF1A=CF1K+CF1M
      CF1B=CF1C+CF1N
      CF2M=PSMY(J)-PIY(J)/386.069*ANSP2
      CF2N=PDMY(J)*ANSP
      CF2A=CF2K+CF2M
      CF2B=CF2C+CF2N
      GO TO 307
  306 CF1=CF1K
      CF2=CF1C
      CF3=CF1D
      CF4=CF1E
      CF5=CF2D
      CF6=CF2E
      CF7=CF2K
      CF8=CF2C
      GO TO 308
  307 CF4=CF2A*CF2A+CF2B*CF2B
      CF1=(CF2A*CF2D+CF2B*CF2E)/CF4
```

```
      CF2=(CF2A*CF2E-CF2B*CF2D)/CF4
      CF3=(CF2A*CF2M+CF2B*CF2N)/CF4
      CF4=(CF2A*CF2N-CF2B*CF2M)/CF4
      CF5=CF1A-CF1*CF1D+CF2*CF1E
      CF6=CF1B-CF2*CF1D-CF1*CF1E
      CF7=-CF3*CF1D+CF4*CF1E
      CF8=-CF4*CF1D-CF3*CF1E
      CF2N=CF5*CF5+CF6*CF6
      CF2A=(CF5*CF1M+CF6*CF1N)/CF2N
      CF2B=(CF5*CF1N-CF6*CF1M)/CF2N
      CF2M=(CF5*CF7+CF6*CF8)/CF2N
      CF2N=(CF5*CF8-CF6*CF7)/CF2N
      CF1A=-CF1*CF2A+CF2*CF2B
      CF1B=CF1*CF2B+CF2*CF2A
      CF1M=CF3-CF1*CF2M+CF2*CF2N
      CF1N=CF4-CF1*CF2N-CF2*CF2M
      CF1=CF1K*CF2A-CF1C*CF2B+CF1D*CF1A+CF1E*CF1B
      CF2=CF1K*CF2B+CF1C*CF2A-CF1D*CF1B+CF1E*CF1A
      CF3=CF1K*CF2M-CF1C*CF2N+CF1D*CF1M-CF1E*CF1N
      CF4=CF1K*CF2N+CF1C*CF2M+CF1D*CF1N+CF1E*CF1M
      CF5=CF2D*CF2A-CF2E*CF2B+CF2K*CF1A+CF2C*CF1B
      CF6=CF2D*CF2B+CF2E*CF2A-CF2K*CF1B+CF2C*CF1A
      CF7=CF2D*CF2M-CF2E*CF2N+CF2K*CF1M-CF2C*CF1N
      CF8=CF2D*CF2N+CF2E*CF2M+CF2K*CF1N+CF2C*CF1M
  308 IF(KFN) 310,309,310
  309 DVXA(KST)=DVXA(KST)-CF1/AMS
      DVXB(KST)=CF2/AMS
      DVXC(KST)=CF3/AMS
      DVXD(KST)=CF4/AMS
      DVYA(KST)=DVYA(KST)-CF7/AMS
      DVYB(KST)=CF8/AMS
      DVYC(KST)=CF5/AMS
      DVYD(KST)=CF6/AMS
      IF(NMOM) 304,311,304
  310 DMXA(KST)=CF1/AMS
      DMXB(KST)=CF2/AMS
      DMXC(KST)=CF3/AMS
      DMXD(KST)=CF4/AMS
      DMYA(KST)=CF7/AMS
      DMYB(KST)=CF8/AMS
      DMYC(KST)=CF5/AMS
      DMYD(KST)=CF6/AMS
  311 CONTINUE
      IF(NDIAG) 312,313,312
C                    DIAGNOSTIC 1
  312 WRITE (6,135)
      WRITE (6,109)CF1K,CF1C,CF1D,CF1E,CF2K,CF2C,CF2D,CF2E,   CF2A,CF2B,C
     1F2M,CF2N,CF1A,CF1B,CF1M,CF1N,CF1,CF2,CF3,CF4,CF5,CF6,   CF7,CF8,STF
     2,ANSP2,ANSP,SPCAL
      WRITE (6,118)KST,KFN
      WRITE (6,144)(DVXA(J),DVXB(J),DVXC(J),DVXD(J),DVYA(J),  DVYB(J),DVY
     1C(J),DVYD(J),J=1,NS),(DMXA(J),DMXB(J),DMXC(J),DMXD(J),  DMYA(J),DMY
     2B(J),DMYC(J),DMYD(J),J=1,NS)
      WRITE (6,145)(RM(J),RIP(J),HIT(J),AN(J),BN(J),DN(J),    J=1,NS)
  313 RETURN
      END
$IBFTC ARCT     M94,XR7
C                    ARCTAN ROUTINE
      FUNCTION ANG(AFCS,AFSN)
      ACS=AFCS
      ASN=AFSN
  800 IF(ASN) 804,801,804
  801 IF(ACS) 802,803,803
```

```
  802 ANG=180.0
      GO TO 812
  803 ANG=0.0
      GO TO 812
  804 IF(ACS) 809,805,808
  805 IF(ASN) 806,803,807
  806 ANG=-90.0
      GO TO 812
  807 ANG=90.0
      GO TO 812
  808 ANG=0.0
      GO TO 810
  809 ANG=-180.0
  810 ASN=ASN/ACS
      ACS=ABS(ASN)
      ACS=ATAN(ACS)
      ANG=ANG+ACS*57.295780
      IF(ASN) 811,812,812
  811 ANG=-ANG
  812 RETURN
      END
$IBFTC EQSS     M94,XR7
      SUBROUTINE EQS
      DIMENSION  A(8,8),B(8,4),C(8,4),D(8,1),CFM(8,8),ENT(10),RHS(8,1),
     1DUM1(100),CLNR(8)
      COMMON   A     , B     , C     , D     , CFM   , ENT
      COMMON   RHS   , DUM1  , CF9   , MAT   , KFN   , CLNR
      COMMON   PRN3
      KFN=KFN
      KFN=1
      GO TO (240,260,260,280),MAT
  240 DO 254 J=1,4
      PRNR=1.0
      PRN2=0.0
      PRN3=1.0
      PRN4=0.0
      K4=0
      DO 248 I=1,4
      PRN1=A(I,J)
      IF(PRN1) 242,241,243
  241 PRN2=PRN2+1.0
      GO TO 244
  242 PRN1=-PRN1
  243 PRNR=PRNR*(PRN1**0.25)
  244 PRN1=B(I,J)
      IF(PRN1) 246,245,247
  245 PRN4=PRN4+1.0
      K4=K4+1
      GO TO 248
  246 PRN1=-PRN1
  247 PRN3=PRN3*(PRN1**0.25)
  248 CONTINUE
      IF(PRN2) 250,250,249
  249 PRN2=4.0/(4.0-PRN2)
      PRNR=PRNR**PRN2
  250 CLNR(J)=PRNR
      IF(PRN4) 252,252,251
  251 IF(K4-4) 257,252,252
  257 PRN4=4.0/(4.0-PRN4)
      PRN3=PRN3**PRN4
  252 DUM1(J)=PRN3
      DO 253 I=1,4
      A(I,J)=A(I,J)/PRNR
```

```
  253 B(I,J)=B(I,J)/PRN3
  254 CONTINUE
      CALL MATINV(A,4,B,4,CF9)
      DO 256 J=1,4
      PRN1=DUM1(J)
      DO 255 I=1,4
  255 A(I,J)=B(I,J)/CLNR(I)*PRN1
  256 CONTINUE
      GO TO 297
  260 PRN3=1.0
      PRN4=0.0
      K4=0
      DO 271 J=1,4
      PRNR=1.0
      PRN2=0.0
      DO 264 I=1,4
      PRN1=C(I,J)
      IF(PRN1) 262,261,263
  261 PRN2=PRN2+1.0
      GO TO 264
  262 PRN1=-PRN1
  263 PRNR=PRNR*(PRN1**0.25)
  264 CONTINUE
      IF(PRN2) 266,266,265
  265 PRN2=4.0/(4.0-PRN2)
      PRNR=PRNR**PRN2
  266 CLNR(J)=PRNR
      DO 267 I=1,4
  267 C(I,J)=C(I,J)/PRNR
      PRN1=D(J,1)
      IF(PRN1) 269,268,270
  268 PRN4=PRN4+1.0
      K4=K4+1
      GO TO 271
  269 PRN1=-PRN1
  270 PRN3=PRN3*(PRN1**0.25)
  271 CONTINUE
      IF(PRN4) 273,273,272
  272 IF(K4-4) 277,273,273
  277 PRN4=4.0/(4.0-PRN4)
      PRN3=PRN3**PRN4
  273 DO 274 J=1,4
  274 D(J,1)=D(J,1)/PRN3
      CALL MATINV(C,4,D,1,CF9)
  275 DO 276 I=1,4
  276 C(I,1)=D(I,1)/CLNR(I)*PRN3
      GO TO 297
  280 PRN3=1.0
      PRN4=0.0
      K4=0
      DO 291 J=1,8
      PRNR=1.0
      PRN2=0.0
      DO 284 I=1,8
      PRN1=CFM(I,J)
      IF (PRN1) 282,281,283
  281 PRN2=PRN2+1.0
      GO TO 284
  282 PRN1=-PRN1
  283 PRNR=PRNR*(PRN1**0.125)
  284 CONTINUE
      IF (PRN2) 286,286,285
  285 PRN2=8.0/(8.0-PRN2)
```

```
      PRNR=PRNR**PRN2
  286 CLNR(J)=PRNR
      DO 287 I=1,8
  287 CFM(I,J)=CFM(I,J)/PRNR
      PRN1=RHS(J,1)
      IF (PRN1) 289,288,290
  288 PRN4=PRN4+1.0
      K4=K4+1
      GO TO 291
  289 PRN1=-PRN1
  290 PRN3=PRN3*(PRN1**0.125)
  291 CONTINUE
      IF (PRN4) 293,293,292
  292 IF(K4-8) 298,293,293
  298 PRN4=8.0/(8.0-PRN4)
      PRN3=PRN3**PRN4
  293 DO 294 J=1,8
  294 RHS(J,1)=RHS(J,1)/PRN3
      CALL MATINV(CFM,8,RHS,1,CF9)
  295 DO 296 I=1,8
  296 CFM(I,1)=RHS(I,1)/CLNR(I)*PRN3
  297 RETURN
      END
$IBFTC MATRIX  M94,XR7
C     MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C
      SUBROUTINE MATINV(A,N,B,M,DETERM)
C
      DIMENSION IPIVOT(8 ), A(8,8  ), B(8,4 ), INDEX(8,2 ), PIVOT(8 )
      EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX, T, SWAP)
C
C     INITIALIZATION
C
   10 DETERM=1.0
   15 DO 20 J=1,N
   20 IPIVOT(J)=0
   30 DO 550 I=1,N
C
C     SEARCH FOR PIVOT ELEMENT
C
   40 AMAX=0.0
   45 DO 105 J=1,N
   50 IF (IPIVOT(J)-1) 60, 105, 60
   60 DO 100 K=1,N
   70 IF (IPIVOT(K)-1) 80, 100, 740
   80 IF (ABS(AMAX)-ABS(A(J,K))) 85, 100, 100
   85 IROW=J
   90 ICOLUM=K
   95 AMAX=A(J,K)
  100 CONTINUE
  105 CONTINUE
  110 IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
C
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
  130 IF (IROW-ICOLUM) 140, 260, 140
  140 DETERM=-DETERM
  150 DO 200 L=1,N
  160 SWAP=A(IROW,L)
  170 A(IROW,L)=A(ICOLUM,L)
  200 A(ICOLUM,L)=SWAP
  205 IF(M) 260, 260, 210
  210 DO 250 L=1, M
```

```
  220 SWAP=B(IROW,L)
  230 B(IROW,L)=B(ICOLUM,L)
  250 B(ICOLUM,L)=SWAP
  260 INDEX(I,1)=IROW
  270 INDEX(I,2)=ICOLUM
  310 PIVOT(I)=A(ICOLUM,ICOLUM)
  320 DETERM=DETERM*PIVOT(I)
C
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
  330 A(ICOLUM,ICOLUM)=1.0
  340 DO 350 L=1,N
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT(I)
  355 IF(M) 380, 380, 360
  360 DO 370 L=1,M
  370 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT(I)
C
C     REDUCE NON-PIVOT ROWS
C
  380 DO 550 L1=1,N
  390 IF(L1-ICOLUM) 400, 550, 400
  400 T=A(L1,ICOLUM)
  420 A(L1,ICOLUM)=0.0
  430 DO 450 L=1,N
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
  455 IF(M) 550, 550, 460
  460 DO 500 L=1,M
  500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
  550 CONTINUE
C
C     INTERCHANGE COLUMNS
C
  600 DO 710 I=1,N
  610 L=N+1-I
  620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
  630 JROW=INDEX(L,1)
  640 JCOLUM=INDEX(L,2)
  650 DO 705 K=1,N
  660 SWAP=A(K,JROW)
  670 A(K,JROW)=A(K,JCOLUM)
  700 A(K,JCOLUM)=SWAP
  705 CONTINUE
  710 CONTINUE
  740 RETURN
  750 END
-     END OF FILE
```

```
SAMPLE CALCULATION NO.1
ROTOR IN RIGID PEDESTALS,NO GYROSCOPIC MOMENT
  27    4    1    0    0    0    0    1    0    0
 3.1300000E+07  1.0000000E+00
 7.600000E+01   3.750000E+00   5.250000E+01
 2.140000E+01   4.090000E+00   4.880000E+01
 3.000000E+01   5.310000E+00   4.860000E+01
 1.250000E+02   5.620000E+00   1.440000E+02
 1.240000E+02   2.250000E+00   3.020000E+02
 3.820000E+02   5.910000E+00   7.788000E+02
 3.760000E+02   9.780000E+00   2.580000E+03
 7.770000E+02   7.190000E+00   8.380000E+02
 5.700000E+02   6.570000E+00   3.950000E+02
 4.530000E+02   7.190000E+00   3.850000E+02
 2.350000E+02   5.000000E+00   3.210000E+02
 3.000000E+02   6.620000E+00   6.130000E+02
 3.130000E+02   4.870000E+00   1.930000E+02
 8.200000E+01   2.130000E+00   6.800000E+01
 3.200000E+01   3.190000E+00   4.180000E+01
 3.672000E+01   7.420000E+00   2.000000E+01
 2.821000E+01   8.650000E+00   5.476000E+00
 9.043000E+01   1.237500E+01   3.120000E-01
 4.297000E+00   1.237500E+00   3.120000E-01
 4.297000E+00   1.237500E+00   3.120000E-01
 7.852000E+01   4.750000E+00   2.000000E+01
 3.423000E+01   5.320000E+00   1.092000E+02
 9.820000E+01   6.190000E+00   8.540000E+02
 2.431000E+02   6.510000E+00   1.602000E+03
 3.300000E+02   6.210000E+00   8.360000E+02
 2.843000E+02   4.330000E+00   1.554000E+02
 6.370000E+01   0.000000E+00   0.000000E+00
   3   16   22   27
  10   1.0000000E+01   0.0000000E+00
 1.000000E+03   5.100000E+03   2.000000E+03
 1.542000E+06   0.000000E+00   0.000000E+00
 3.362000E+06   0.000000E+00   0.000000E+00
-8.010000E+05   0.000000E+00   0.000000E+00
 1.302000E+06   0.000000E+00   0.000000E+00
 1.542000E+05   0.000000E+00   0.000000E+00
 1.040000E+06   0.000000E+00   0.000000E+00
 9.720000E+05   0.000000E+00   0.000000E+00
 1.302000E+06   0.000000E+00   0.000000E+00
 1.542000E+06   0.000000E+00   0.000000E+00
 3.362000E+06   0.000000E+00   0.000000E+00
-8.010000E+05   0.000000E+00   0.000000E+00
 1.302000E+06   0.000000E+00   0.000000E+00
 1.542000E+05   0.000000E+00   0.000000E+00
 1.040000E+06   0.000000E+00   0.000000E+00
 9.720000E+05   0.000000E+00   0.000000E+00
 1.302000E+06   0.000000E+00   0.000000E+00
 1.463000E+06   0.000000E+00   0.000000E+00
 3.296000E+06   0.000000E+00   0.000000E+00
-1.045000E+06   0.000000E+00   0.000000E+00
 1.781000E+06   0.000000E+00   0.000000E+00
-1.197000E+05   0.000000E+00   0.000000E+00
 1.754000E+06   0.000000E+00   0.000000E+00
 1.175000E+06   0.000000E+00   0.000000E+00
 1.781000E+06   0.000000E+00   0.000000E+00
 1.463000E+06   0.000000E+00   0.000000E+00
 3.296000E+06   0.000000E+00   0.000000E+00
-1.045000E+06   0.000000E+00   0.000000E+00
 1.781000E+06   0.000000E+00   0.000000E+00
-1.197000E+05   0.000000E+00   0.000000E+00
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1.754000E+06	0.000000E+00	0.000000E+00
1.175900E+05	0.000000E+00	0.000000E+00
1.781000E+06	0.000000E+00	0.000000E+00

UNBALANCE RESPONSE OF ROTOR WITH NON-UNIFORM BEARING SUPPORTS PN0011
MECHANICAL TECHNOLOGY,INC.

SAMPLE CALCULATION NO.1
ROTOR IN RIGID PEDESTALS,NO GYROSCOPIC MOMENT

STATIONS	NO.BRGS.	NO.UNBAL.	NO.COUPL.	PED.FLEX.	BRG.MOMENT	GYRO.MOM.	NO.CASES	DIAGNOSTIC	INPUT
27	4	1	0	0	0	0	1	0	0

YOUNGS MODULUS	SCALE FACTOR
3.1300000E 07	1.0000000E 00

ROTOR DATA

STATION NO.	MASS	LENGTH	CROSS SECT.INERTIA
1	7.6000000E 01	3.7500000E 00	5.2499999E 01
2	2.1400000E 01	4.0900000E 00	4.8799999E 01
3	3.0000000E 01	5.3099999E 00	4.8799999E 01
4	1.2500000E 02	6.6199999E 00	1.4400000E 02
5	1.2400000E 02	2.2500000E 00	3.0200000E 02
6	3.8200000E 02	5.9100000E 00	7.7879999E 02
7	8.7600000E 02	9.7800000E 00	2.5800000E 03
8	7.7700000E 02	7.1900000E 00	8.3800000E 02
9	5.7000000E 02	8.5699999E 00	3.9500000E 02
10	4.5300000E 02	7.1900000E 00	3.8500000E 02
11	2.3500000E 02	5.0000000E 00	3.2100000E 02
12	3.0000000E 02	6.6199999E 00	6.1300000E 02
13	3.1300000E 02	4.8699999E 00	1.9300000E 02
14	8.1999999E 01	2.1300000E 00	6.8000000E 01
15	3.2000000E 01	3.1900000E 00	4.1799999E 01
16	3.6720000E 01	7.4200000E 00	2.0000000E 01
17	2.8210000E 01	8.6500000E 00	5.4760000E 00
18	9.0429999E 01	1.2375000E 01	3.1200000E-01
19	4.2970000E 00	1.2375000E 00	3.1200000E-01
20	4.2970000E 00	1.2375000E 00	3.1200000E-01
21	7.8519999E 01	4.7500000E 00	2.0000000E 01
22	3.4229999E 01	5.3200000E 00	1.0920000E 02
23	9.8199999E 01	6.1900000E 00	8.5400000E 02
24	2.4310000E 02	6.5100000E 00	1.6020000E 03
25	3.3000000E 02	6.2100000E 00	8.3599999E 02
26	2.8430000E 02	4.3300000E 00	1.5540000E 02
27	6.3499999E 01	0.	0.

BEARING STATIONS
3 16 22 27

UNBALANCE ST.	X-UNBALANCE	Y-UNBALANCE
10	1.0000000E 01	0.

INITIAL SPEED	FINAL SPEED	SPEED INCR.
1.000000E 03	5.100000E 03	2.000000E 03

BEARING AT STATION NO. 3

KXX	CXX	KXY	CXY	KYY	CYY	KYX	CYX
1.542000E 06	3.362000E 06	-8.010000E 05	1.302000E 06	1.542000E 05	1.040000E 06	9.720000E 05	1.302000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 16

KXX	CXX	KXY	CXY	KYY	CYY	KYX	CYX
1.542000E 06	3.362000E 04	-8.010000E 05	1.302000E 06	1.542000E 05	1.040000E 06	9.720000E 05	1.302000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 22

KXX	CXX	KXY	CXY	KYY	CYY	KYX	CYX
1.463000E 06	3.296000E 06	-1.045000E 06	1.781000E 06	-1.197000E 05	1.754000E 06	1.175000E 06	1.781000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 27

KXX	CXX	KXY	CXY	KYY	CYY	KYX	CYX
1.463000E 06	3.296000E 06	-1.045000E 06	1.781000E 06	-1.197000E 05	1.754000E 06	1.175000E 06	1.781000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

ROTOR SPEED= 1.0000000E 03RPM

AMPLITUDE

STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
1	1.39030E-02	-3.56166E-03	8.83056E 01	-6.00124E 00
2	1.44877E-02	-3.64268E-03	-8.24256E 01	3.85389E 00
3	1.57165E-02	-3.14360E-03	-7.41771E 01	1.26949E 01
4	1.77963E-02	-1.99191E-03	-6.73332E 01	2.02376E 01
5	2.02743E-02	-5.52424E-04	-6.32125E 01	2.51267E 01
6	2.10188E-02	-1.30511E-04	-6.24077E 01	2.61720E 01
7	2.28630E-02	6.97364E-04	-6.09964E 01	2.82804E 01
8	2.57277E-02	2.45862E-03	-5.93827E 01	3.06820E 01
9	2.75485E-02	3.37057E-03	-5.88331E 01	3.18730E 01
10	2.85957E-02	3.49158E-03	-5.91351E 01	3.21666E 01
11	2.81163E-02	2.40871E-03	-6.04866E 01	3.13158E 01
12	2.71513E-02	1.11387E-03	-6.21560E 01	2.99776E 01
13	2.54653E-02	-9.21174E-04	-6.54592E 01	2.70966E 01
14	2.40795E-02	-2.49571E-03	-6.90475E 01	2.38066E 01
15	2.34274E-02	-3.19155E-03	-7.11461E 01	2.18327E 01
16	2.24164E-02	-4.17627E-03	-7.51407E 01	1.80098E 01
17	2.04700E-02	-5.38908E-03	-8.70756E 01	6.33905E 00
18	1.83579E-02	-4.38640E-03	7.82289E 01	-8.52867E 00
19	2.18092E-03	-4.03484E-04	8.74280E 01	-3.40966E 01
20	1.39982E-03	-4.11679E-04	-8.21965E 01	-4.57242E 01
21	1.11667E-03	-4.64966E-04	-7.58186E 01	-5.29738E 01
22	8.57024E-04	-4.25363E-04	-7.20060E 01	-5.53575E 01
23	6.44014E-04	-3.34198E-04	-7.01691E 01	-5.50956E 01

BENDING MOMENT

MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
0.	0.	0.	0.
0.	-0.	0.	0.
1.12550E-01	-2.88330E-02	8.83056E 01	-6.00124E 00
1.12550E-01	-2.88330E-02	8.83056E 01	-6.00124E 00
2.70675E-01	-6.99821E-02	8.95281E 01	-4.70114E 00
2.70675E-01	-6.99821E-02	8.95281E 01	-4.70114E 00
4.44200E 01	3.59123E 01	-4.72744E 01	4.37527E 01
4.44200E 01	3.59123E 01	-4.72744E 01	4.37527E 01
9.96397E 01	8.05669E 01	-4.72571E 01	4.37374E 01
9.96397E 01	8.05669E 01	-4.72571E 01	4.37374E 01
1.18261E 02	9.57621E 01	-4.72528E 01	4.37570E 01
1.18261E 02	9.57621E 01	-4.72528E 01	4.37570E 01
1.65933E 02	1.35790E 02	-4.72325E 01	4.39119E 01
1.65933E 02	1.35790E 02	-4.72325E 01	4.39119E 01
2.39638E 02	2.02187E 02	-4.71864E 01	4.43731E 01
2.39638E 02	2.02187E 02	-4.71864E 01	4.43731E 01
2.89980E 02	2.50845E 02	-4.71668E 01	4.47685E 01
2.89980E 02	2.50845E 02	-4.71668E 01	4.47685E 01
3.46376E 02	3.08586E 02	-4.72006E 01	4.52923E 01
3.46376E 02	3.08586E 02	-4.72006E 01	4.52923E 01
2.63627E 02	2.29285E 02	-4.77030E 01	4.54036E 01
2.63627E 02	2.29285E 02	-4.77030E 01	4.54036E 01
2.05211E 02	1.74121E 02	-4.81803E 01	4.54809E 01
2.05211E 02	1.74121E 02	-4.81803E 01	4.54809E 01
1.26467E 02	1.01144E 02	-4.91972E 01	4.55485E 01
1.26467E 02	1.01144E 02	-4.91972E 01	4.55485E 01
6.75908E 01	4.76421E 01	-5.08808E 01	4.52338E 01
6.75908E 01	4.76421E 01	-5.08808E 01	4.52338E 01
4.18095E 01	2.43378E 01	-5.28014E 01	4.42054E 01
4.18095E 01	2.43378E 01	-5.28014E 01	4.42054E 01
1.25434E 01	-1.15343E 00	6.16690E 01	-1.93548E 01
1.25434E 01	-1.15343E 00	6.16690E 01	-1.93548E 01
8.75306E 00	-7.66293E-01	6.15569E 01	-1.96470E 01
8.75306E 00	-7.66293E-01	6.15569E 01	-1.96470E 01
4.21940E 00	-2.51842E-01	6.04563E 01	-2.11744E 01
4.21940E 00	-2.51842E-01	6.04563E 01	-2.11744E 01
2.87531E 00	-5.95496E-01	6.97393E 01	-1.12866E 01
2.87531E 00	-5.95496E-01	6.97393E 01	-1.12866E 01
3.57571E 00	-6.89892E-01	6.84754E 01	-1.26143E 01
3.57571E 00	-6.89892E-01	6.84754E 01	-1.26143E 01
4.27813E 00	-7.82237E-01	6.76525E 01	-1.34830E 01
4.27813E 00	-7.82237E-01	6.76525E 01	-1.34830E 01
6.98599E 00	-1.12831E 00	6.61646E 01	-1.51876E 01
6.98599E 00	-1.12831E 00	6.61646E 01	-1.51876E 01
5.74537E 00	-8.75143E-01	6.54791E 01	-1.51402E 01
5.74537E 00	-8.75143E-01	6.54791E 01	-1.51402E 01

24	4.10740E-04	-2.18190E-04	-6.81780E 01	-5.20223E 01	4.35583E 00	-7.48033E-01	6.42444E 01	-1.48810E 01
					4.35583E 00	-7.48033E-01	6.42444E 01	-1.48810E 01
25	1.73559E-04	-9.74245E-05	-5.80558E 01	-4.02266E 01	2.79182E 00	-7.54467E-01	5.98641E 01	-1.66316E 01
					2.79182E 00	-7.54467E-01	5.98641E 01	-1.66316E 01
26	7.63932E-05	-1.75802E-05	-8.73840E 01	-8.79655E 01	1.57026E 00	-6.62803E-01	4.38060E 01	-2.43181E 01
					1.57026E 00	-6.62803E-01	4.38060E 01	-2.43181E 01
27	2.37679E-04	-1.12993E-04	-7.96813E 01	-7.22591E 01	3.21715E-01	-2.21590E-01	3.96902F 01	-1.91341F 01
					3.21715E-01	-2.21590E-01	3.96902F 01	-1.91341E 01

FORCE TRANSMITTED TO BEARING HOUSING

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	8.43201E 00	6.70134E 00	-4.72276E 01	4.34201E 01	7.54892E 00	2.75484E 00	7.68249E 00	-1.02552E 01
16	1.20823E 01	1.14087E 01	-4.15562E 01	4.05873E 01	1.17906E 01	6.56143E-01	1.17098E 01	-2.60517E 00
22	8.07698E-01	-1.18499E-01	6.52614E 01	-1.80327E 01	3.54725E-01	1.44305E 02	7.35247E-01	-1.04165E 02
27	3.03706E-01	1.08020E-02	5.90307E 01	-6.96806E 00	1.56555E-01	-3.57633E 00	2.60470E-01	8.18091E 01

ENERGY INPUT= 8.1158408E-04 ENERGY DISSIPATED= 8.1159989E-04

ROTOR SPEED= 3.0000000E 03RPM

	AMPLITUDE				BENDING MOMENT			
STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
1	2.25113E-01	-1.20761E-02	-6.53596E 01	7.06737E 01	0.	0.	0.	0.
					0.	-0.	0.	0.
2	2.22621E-01	-4.12056E-02	-6.41933E 01	7.58705E 01	1.64014E 01	-8.79843E-01	-6.53596E 01	7.06737E 01
					1.64014E 01	-8.79843E-01	-6.53596E 01	7.06737E 01
3	2.22508E-01	-7.17660E-02	-6.10487E 01	8.25551E 01	3.92537E 01	-2.76629E 00	-6.52893E 01	7.13099E 01
					3.92537E 01	-2.76629E 00	-6.52893E 01	7.13099E 01
4	2.27319E-01	-1.04808E-01	-5.37431E 01	-8.66328E 01	9.93888E 02	-1.54137E 02	-2.65076E 00	-2.63657E 01
					9.93888E 02	-1.54137E 02	-2.65076E 00	-2.63657E 01
5	2.37905E-01	-1.26332E-01	-4.28350E 01	-7.26149E 01	2.20906E 03	-3.50189E 02	-2.60913E 00	-2.64684E 01
					2.20906E 03	-3.50189E 02	-2.60913E 00	-2.64684E 01
6	2.41845E-01	-1.29361E-01	-3.95670E 01	-6.84684E 01	2.60890E 03	-4.04149E 02	-2.52602E 00	-2.63530E 01
					2.60890E 03	-4.04149E 02	-2.52602E 00	-2.63530E 01
7	2.53626E-01	-1.31873E-01	-3.23703E 01	-5.91497E 01	3.54693E 03	-4.44783E 02	-1.94408E 00	-2.54447E 01
					3.54693E 03	-4.44783E 02	-1.94408E 00	-2.54447E 01
8	2.76827E-01	-1.26514E-01	-2.46449E 01	-4.82487E 01	4.62679E 03	-1.42208E 02	-2.63920E-01	-2.28431E 01
					4.62679E 03	-1.42208E 02	-2.63920E-01	-2.28431E 01
9	2.92014E-01	-1.18514E-01	-2.18218E 01	-4.32519E 01	5.07213E 03	3.06927E 02	1.17151E 00	-2.07164E 01
					5.07213E 03	3.06927E 02	1.17151E 00	-2.07164E 01
10	2.93920E-01	-1.06701E-01	-2.19397E 01	-4.07448E 01	5.28573E 03	1.03679E 03	2.94429E 00	-1.80740E 01
					5.28573E 03	1.03679E 03	2.94429E 00	-1.80740E 01
11	2.77009E-01	-9.64618E-02	-2.54143E 01	-4.16787E 01	4.14477E 03	6.61495E 02	1.73308E 00	-1.84990E 01
					4.14477E 03	6.61495E 02	1.73308E 00	-1.84990E 01
12	2.57237E-01	-8.82535E-02	-2.99613E 01	-4.40639E 01	3.27966E 03	4.40290E 02	7.56919E-01	-1.88137E 01
					3.27966E 03	4.40290E 02	7.56919E-01	-1.88137E 01
13	2.27914E-01	-7.36636E-02	-3.88404E 01	-4.92526E 01	2.02467E 03	2.11765E 02	-7.46050E-01	-1.91622E 01
					2.02467E 03	2.11765E 02	-7.46050E-01	-1.91622E 01
14	2.07438E-01	-5.81558E-02	-4.76064E 01	-5.43428E 01	1.03342E 03	9.12326E 01	-2.35901E 00	-1.92107E 01
					1.03342E 03	9.12326E 01	-2.35901E 00	-1.92107E 01
15	1.99113E-01	-4.92778E-02	-5.21554E 01	-5.68612E 01	5.94199E 02	4.38652E 01	-4.35613E 00	-1.91705E 01
					5.94199E 02	4.38652E 01	-4.35613E 00	-1.91705E 01
16	1.88003E-01	-3.29200E-02	-5.96697E 01	-6.06174E 01	8.46701E 01	2.00979E 01	3.57348E 01	-2.84783E 01
					8.46701E 01	2.00979E 01	3.57348E 01	-2.84783E 01
17	1.72623E-01	1.08120E-02	-7.65800E 01	-6.48289E 01	6.80213E 01	2.18212E 01	4.41070E 01	-3.30327E 01
					6.80213E 01	2.18212E 01	4.41070E 01	-3.30327E 01
18	1.62381E-01	5.33585E-02	8.37872E 01	-5.99221E 01	4.51754E 01	1.74567E 01	5.24506E 01	-3.87729E 01
					4.51754E 01	1.74567E 01	5.24506E 01	-3.87729E 01
19	1.74169E-02	7.73079E-03	-7.23095E 01	7.65460E 01	2.76037E 01	9.65416E 00	7.07763E 01	-4.92717E 01
					2.76037E 01	9.65416E 00	7.07763E 01	-4.92717E 01
20	1.22379E-02	1.00904E-03	-6.49984E 01	5.51075E 01	3.47204E 01	1.25093E 01	6.85407E 01	-4.80815F 01
					3.47204E 01	1.25093E 01	6.85407E 01	-4.80815E 01

21	1.05025E-02	-1.71160E-03	-6.84949E 01	4.31113E 01	4.18719E 01	1.53511E 01	6.70562E 01	-4.72862E 01
					4.18719E 01	1.53511E 01	6.70562E 01	-4.72862E 01
22	8.44241E-03	-2.30981E-03	-7.42452E 01	3.56103E 01	6.93213E 01	2.69244E 01	6.44931E 01	-4.63859E 01
					6.93213E 01	2.69244E 01	6.44931E 01	-4.63859E 01
23	6.50403E-03	-2.05238E-03	-7.69285E 01	3.37688E 01	5.38153E 01	2.05519E 01	6.82131E 01	-4.35408E 01
					5.38153E 01	2.05519E 01	6.82131E 01	-4.35408E 01
24	4.29383E-03	-1.52242E-03	-8.15433E 01	3.23991E 01	3.45171E 01	2.06931E 01	7.27444E 01	-3.31298E 01
					3.45171E 01	2.06931E 01	7.27444E 01	-3.31298E 01
25	2.04262E-03	-9.21702E-04	8.18132E 01	2.58433E 01	2.09304E 01	1.69495E 01	8.17431E 01	-1.50193E 01
					2.09304E 01	1.69495E 01	8.17431E 01	-1.50193E 01
26	9.80178E-04	7.85178E-05	-3.19948E 00	6.29771E 00	2.41078E 01	1.58705E 01	9.33294E 00	8.86198E 01
					2.41078E 01	1.58705E 01	9.33294E 00	8.86198E 01
27	1.96710E-03	-1.69705E-05	-5.61997E 01	2.57598E 01	3.08114E 01	7.60778E 00	2.24937E 01	-8.62829E 01
					3.08114E 01	7.60778E 00	2.24937E 01	-8.62829E 01

FORCE TRANSMITTED TO BEARING HOUSING

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.89720E 02	-4.18999E 01	-3.52855E 00	-2.85199E 01	1.89378E 02	-2.77397E 01	4.34199E 01	1.67080E 02
16	2.10954E 02	1.95094E 01	-8.30463E-03	-1.96138E 01	2.10954E 02	-1.96146E 01	1.98094E 01	-1.97023E 01
22	8.78956E 00	3.34633E 00	5.96146E 01	-5.13469E 01	5.30084E 00	1.61648E 02	7.76887E 00	-1.53931E 02
27	3.42944E 00	1.09874E 00	1.96414E 01	3.32119E 01	3.25094E 00	3.97351E 01	1.54908E 00	8.12978E 01

ENERGY INPUT= 8.3496344E-02 ENERGY DISSIPATED= 8.3500748E-02

ROTOR SPEED= 5.0000000E 03RPM

	AMPLITUDE				BENDING MOMENT			
STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
1	3.69461E-01	3.18251E-01	3.96219E 01	7.21398E 01	0.	0.	0.	0.
					0.	-0.	0.	0.
2	2.96381E-01	2.07587E-01	-3.89226E 01	-1.38118E 01	7.47731E 01	6.44091E 01	3.96219E 01	7.21398E 01
					7.47731E 01	6.44091E 01	3.96219E 01	7.21398E 01
3	3.14480E-01	7.34460E-02	-2.42506E 01	2.56868E 00	1.68744E 02	1.52533E 02	3.91108E 01	7.41443E 01
					1.68744E 02	1.52533E 02	3.91108E 01	7.41443E 01
4	4.39942E-01	1.82067E-02	-2.95821E 00	2.42929E 01	6.35129E 03	8.85621E 02	2.19590E 01	4.95654E 01
					6.35129E 03	8.85621E 02	2.19590E 01	4.95654E 01
5	6.12675E-01	4.40158E-02	8.05374E 00	3.56832E 01	1.39000E 04	1.88807E 03	2.18531E 01	4.94543E 01
					1.39000E 04	1.88807E 03	2.18531E 01	4.94543E 01
6	6.56664E-01	5.87874E-02	9.30958E 00	3.73761E 01	1.63518E 04	2.22745E 03	2.19320E 01	4.95339E 01
					1.63518E 04	2.22745E 03	2.19320E 01	4.95339E 01
7	7.54378E-01	9.83087E-02	1.32927E 01	4.08392E 01	2.17929E 04	3.07847E 03	2.26012E 01	5.02112E 01
					2.17929E 04	3.07847E 03	2.26012E 01	5.02112E 01
8	8.87827E-01	1.67624E-01	1.66985E 01	4.43520E 01	2.63951E 04	4.07626E 03	2.48350E 01	5.24649E 01
					2.63951E 04	4.07626E 03	2.48350E 01	5.24649E 01
9	9.53177E-01	2.16944E-01	1.82077E 01	4.59323E 01	2.64232E 04	4.31165E 03	2.72588E 01	5.48980E 01
					2.64232E 04	4.31165E 03	2.72588E 01	5.48980E 01
10	9.29264E-01	2.62879E-01	1.87900E 01	4.66177E 01	2.34855E 04	4.17494E 03	3.17617E 01	5.94024E 01
					2.34855E 04	4.17494E 03	3.17617E 01	5.94024E 01
11	8.06731E-01	2.88029E-01	1.79498E 01	4.59327E 01	1.91171E 04	3.69775E 03	3.03310E 01	5.79547E 01
					1.91171E 04	3.69775E 03	3.03310E 01	5.79547E 01
12	6.72240E-01	2.99050E-01	1.64008E 01	4.46177E 01	1.54637E 04	3.18315E 03	2.94423E 01	5.70348E 01
					1.54637E 04	3.18315E 03	2.94423E 01	5.70348E 01
13	4.57646E-01	3.11264E-01	1.22341E 01	4.16956E 01	9.75539E 03	2.15687E 03	2.86289E 01	5.60945E 01
					9.75539E 03	2.15687E 03	2.86289E 01	5.60945E 01
14	3.24350E-01	2.83158E-01	-7.80530E 01	-5.79206E 01	5.12270E 03	1.12674E 03	2.88408E 01	5.59402E 01
					5.12270E 03	1.12674E 03	2.88408E 01	5.59402E 01
15	3.33680E-01	2.02699E-01	-8.40872E 01	-5.89729E 01	3.07077E 03	6.45238E 02	2.95186E 01	5.61017E 01
					3.07077E 03	6.45238E 02	2.95186E 01	5.61017E 01
16	3.60323E-01	8.34787E-02	8.71575E 01	-6.65709E 01	1.47461E 02	4.80859E 01	-7.30929E 01	-7.95474E 01
					1.47461E 02	4.80859E 01	-7.30929E 01	-7.95474E 01
17	5.40095E-01	-8.40086E-02	6.11134E 01	8.77301E 01	1.78746E 02	1.34613E 01	[illegible]	[illegible]

18	8.55182E-01	-1.21549E-01	4.66882E 01	7.29325E 01	3.08900E 02	-2.99844E 01	3.89169E 01	6.78332E 01
					3.08900E 02	-2.99844E 01	3.89169E 01	6.78332E 01
19	1.05272E-01	-1.57027E-02	5.87869E 01	5.56783E 01	1.63326E 02	-2.12169E 01	4.15069E 01	7.20501E 01
					1.63326E 02	-2.12169E 01	4.15069E 01	7.20501E 01
20	5.68401E-02	-1.71465E-02	7.32543E 01	4.39006E 01	2.10823E 02	-2.64258E 01	4.11373E 01	7.13910E 01
					2.10823E 02	-2.64258E 01	4.11373E 01	7.13910E 01
21	4.05544E-02	-2.13940E-02	8.59406E 01	3.65630E 01	2.58483E 02	-3.16274E 01	4.09374E 01	7.09543E 01
					2.58483E 02	-3.16274E 01	4.09374E 01	7.09543E 01
22	2.93276E-02	-2.12347E-02	-8.27374E 01	3.57796E 01	4.45606E 02	-5.07780E 01	4.15833E 01	6.93005E 01
					4.45606E 02	-5.07780E 01	4.15833E 01	6.93005E 01
23	2.21186E-02	-1.87502E-02	-6.72217E 01	4.49263E 01	3.63754E 02	-3.64535E 01	4.05170E 01	7.67355E 01
					3.63754E 02	-3.64535E 01	4.05170E 01	7.67355E 01
24	1.43919E-02	-1.30546E-02	-5.45806E 01	5.13101E 01	2.79548E 02	-2.01352E 01	3.87578E 01	8.80541E 01
					2.79548E 02	-2.01352E 01	3.87578E 01	8.80541E 01
25	8.80776E-03	-6.52669E-03	7.45577E 00	-8.50465E 01	1.98177E 02	-2.76374E 01	4.13458E 01	-7.18486E 01
					1.98177E 02	-2.76374E 01	4.13458E 01	-7.18486E 01
26	6.87963E-03	-3.06026E-03	5.02161E 01	7.47993E 01	1.71337E 02	1.37401E 01	3.22071E 01	-3.78272E 01
					1.71337E 02	1.37401E 01	3.22071E 01	-3.78272E 01
27	1.01824E-02	-4.80606E-03	6.90885E 01	5.19171E 01	1.52990E 02	1.62621E 01	3.25760E 01	-7.21276E 00
					1.52990E 02	1.62621E 01	3.25760E 01	-7.21276E 00

FORCE TRANSMITTED TO BEARING HOUSING

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.15853E 03	1.28511E 02	2.02245E 01	4.77805E 01	1.08801E 03	-1.29871E 02	4.18262E 02	-5.89681E 01
16	9.43631E 02	2.49322E 02	2.67030F 01	5.48980E 01	8.50404E 02	-1.17532E 02	4.78973E 02	-6.28135E 01
22	5.61379E 01	-6.49720E 00	4.45372E 01	5.87467E 01	4.02735E 01	5.22498E 01	3.96450E 01	1.55455E 02
27	3.11491E 01	-1.96309E 00	4.50874E 01	-6.95669E 01	2.20360E 01	-7.31840E 01	2.21028E 01	2.40283E 01

ENERGY INPUT= 1.5114504E 00   ENERGY DISSIPATED= 1.5119938E 00

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SAMPLE CALCULATION NO.2
ROTOR IN FLEXIBLE PEDESTALS AND GYROSCOPIC MOMENT
 27    4    3    0    1    1    1    1    0    1
 3.1300000E+07   1.0000000E+00
   7            1.000000E-03
 7.600000E+01   3.750000E+00   5.250000E+01   1.282000E+04   7.110000E+03
 2.140000E+01   4.090000E+00   4.880000E+01   0.000000E+00   0.000000E+00
 3.000000E+01   5.310000E+00   4.880000E+01   0.000000E+00   0.000000E+00
 1.250000E+02   6.620000E+00   1.440000E+02   0.000000E+00   0.000000E+00
 1.240000E+02   2.250000E+00   3.020000E+02   0.000000E+00   0.000000E+00
 3.820000E+02   5.910000E+00   7.788000E+02   0.000000E+00   0.000000E+00
 8.760000E+02   9.780000E+00   2.580000E+03   0.000000E+00   0.000000E+00
 7.770000E+02   7.190000E+00   8.380000E+02   0.000000E+00   0.000000E+00
 5.700000E+02   8.570000E+00   3.950000E+02   0.000000E+00   0.000000E+00
 4.530000E+02   7.190000E+00   3.850000E+02   0.000000E+00   0.000000E+00
 2.350000E+02   5.000000E+00   3.210000E+02   0.000000E+00   0.000000E+00
 3.000000E+02   6.620000E+00   6.130000E+02   0.000000E+00   0.000000E+00
 3.130000E+02   4.870000E+00   1.930000E+02   0.000000E+00   0.000000E+00
 9.200000E+01   2.130000E+00   6.800000E+01   0.000000E+00   0.000000E+00
 3.200000E+01   3.190000E+00   4.180000E+01   0.000000E+00   0.000000E+00
 3.672000E+01   7.420000E+00   2.000000E+01   0.000000E+00   0.000000E+00
 2.821000E+01   8.650000E+00   5.476000E+00   1.820000E+02   9.700000E+01
 9.043000E+01   1.237500E+01   3.120000E-01   1.050000E+03   5.450000E+02
 4.297000E+00   1.237500E+00   3.120000E-01   0.000000E+00   0.000000E+00
 4.297000E+00   1.237500E+00   3.120000E-01   0.000000E+00   0.000000E+00
 7.852000E+01   4.750000E+00   2.000000E+01   1.650000E+03   8.800000E+02
 3.423000E+01   5.320000E+00   1.092000E+02   0.000000E+00   0.000000E+00
 9.820000E+01   6.190000E+00   8.540000E+02   0.000000E+00   0.000000E+00
 2.431000E+02   6.510000E+00   1.602000E+03   0.000000E+00   0.000000E+00
 3.300000E+02   6.210000E+00   8.360000E+02   0.000000E+00   0.000000E+00
 2.843000E+02   4.330000E+00   1.554000E+02   0.000000E+00   0.000000E+00
 6.370000E+01   0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
   3    16    22    27
   1   1.0000000E+01   0.0000000E+00
  10   1.0000000E+01   1.0000000E+01
  18  -1.0000000E+01   0.0000000E+00
 5.2000E+01   8.2000E+05   2.2000E+01   5.2000E+01   5.3000E+05   2.2000E+01
 5.2000E+01   8.2000E+05   2.2000E+01   5.2000E+01   5.3000E+05   2.2000E+01
 4.4000E+01   1.3000E+06   3.4000E+01   4.4000E+01   9.0000E+05   3.4000E+01
 4.4000E+01   1.3000E+06   3.4000E+01   4.4000E+01   9.0000E+05   3.4000E+01
 9.5000E+01   1.7000E+06   1.8000E+01   9.5000E+01   1.3000E+06   1.8000E+01
 9.5000E+01   1.7000E+06   1.8000E+01   9.5000E+01   1.3000E+06   1.8000E+01
 8.5000E+01   1.9000E+06   2.7000E+01   8.5000E+01   1.5000E+06   2.7000E+01
 8.5000E+01   1.9000E+06   2.7000E+01   8.5000E+01   1.5000E+06   2.7000E+01
  1.000000E+03   5.100000E+03   2.000000E+03
  1.542000E+06   0.000000E+00   0.000000E+00
  3.362000E+06   0.000000E+00   0.000000E+00
 -8.010000E+05   0.000000E+00   0.000000E+00
  1.302000E+06   0.000000E+00   0.000000E+00
  1.542000E+05   0.000000E+00   0.000000E+00
  1.040000E+06   0.000000E+00   0.000000E+00
  9.720000E+05   0.000000E+00   0.000000E+00
  1.302000E+06   0.000000E+00   0.000000E+00
  1.542000E+06   0.000000E+00   0.000000E+00
  3.362000E+06   0.000000E+00   0.000000E+00
 -8.010000E+05   0.000000E+00   0.000000E+00
  1.302000E+06   0.000000E+00   0.000000E+00
  1.542000E+05   0.000000E+00   0.000000E+00
  1.040000E+06   0.000000E+00   0.000000E+00
  9.720000E+05   0.000000E+00   0.000000E+00
  1.302000E+06   0.000000E+00   0.000000E+00
  1.463000E+06   0.000000E+00   0.000000E+00
  3.296000E+06   0.000000E+00   0.000000E+00
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-1.045000E+06	0.000000E+00	0.000000E+00
1.761000E+06	0.000000E+00	0.000000E+00
-1.197000E+05	0.000000E+00	0.000000E+00
1.754000E+06	0.000000E+00	0.000000E+00
1.175000E+05	0.000000E+00	0.000000E+00
1.781000E+05	0.000000E+00	0.000000E+00
1.463000E+05	0.000000E+00	0.000000E+00
3.276000E+06	0.000000E+00	0.000000E+00
-1.045000E+06	0.000000E+00	0.000000E+00
1.781000E+05	0.000000E+00	0.000000E+00
-1.197000E+05	0.000000E+00	0.000000E+00
1.754000E+06	0.000000E+00	0.000000E+00
1.175000E+06	0.000000E+00	0.000000E+00
1.781000E+06	0.000000E+00	0.000000E+00
1.070000E+06	0.000000E+00	0.000000E+00
2.240000E+06	0.000000E+00	0.000000E+00
-5.700000E+05	0.000000E+00	0.000000E+00
9.140000E+05	0.000000E+00	0.000000E+00
1.070000E+05	0.000000E+00	0.000000E+00
6.800000E+05	0.000000E+00	0.000000E+00
6.320000E+05	0.000000E+00	0.000000E+00
9.140000E+05	0.000000E+00	0.000000E+00
1.070000E+06	0.000000E+00	0.000000E+00
2.240000E+06	0.000000E+00	0.000000E+00
-5.700000E+05	0.000000E+00	0.000000E+00
9.140000E+05	0.000000E+00	0.000000E+00
1.070000E+05	0.000000E+00	0.000000E+00
6.800000E+05	0.000000E+00	0.000000E+00
6.320000E+05	0.000000E+00	0.000000E+00
9.140000E+05	0.000000E+00	0.000000E+00
9.800000E+05	0.000000E+00	0.000000E+00
2.160000E+06	0.000000E+00	0.000000E+00
-7.000000E+05	0.000000E+00	0.000000E+00
1.330000E+06	0.000000E+00	0.000000E+00
-8.700000E+04	0.000000E+00	0.000000E+00
1.200000E+06	0.000000E+00	0.000000E+00
7.600000E+05	0.000000E+00	0.000000E+00
1.330000E+06	0.000000E+00	0.000000E+00
9.800000E+05	0.000000E+00	0.000000E+00
2.160000E+05	0.000000E+00	0.000000E+00
-7.000000E+05	0.000000E+00	0.000000E+00
1.330000E+06	0.000000E+00	0.000000E+00
-8.700000E+04	0.000000E+00	0.000000E+00
1.200000E+06	0.000000E+00	0.000000E+00
7.600000E+05	0.000000E+00	0.000000E+00
1.330000E+06	0.000000E+00	0.000000E+00

END OF FILE

UNBALANCE RESPONSE OF ROTOR WITH NON-UNIFORM BEARING SUPPORTS [illegible]
MECHANICAL TECHNOLOGY,INC.

SAMPLE CALCULATION NO.2
ROTOR IN FLEXIBLE PEDESTALS AND GYROSCOPIC MOMENT

STATIONS	NO.BRGS.	NO.UNBAL.	NO.COUPL.	PED.FLEX.	BRG.MOMENT	GYRO.MOM.	NO.CASES	DIAGNOSTIC	INPUT
27	4	3	0	1	1	[illegible]	1	0	1

YOUNGS MODULUS	SCALE FACTOR
3.1300000E 07	1.0000000E 03

ITERAT.	ITERAT.CONVERG.LIMIT
7	10.000000E-06

ROTOR DATA

STATION NO.	MASS	LENGTH	CROSS SECT.INERTIA	POLAR MOM.INERTIA	TRANSV.MOM.INERTIA
1	[illegible]	[illegible]	5.2499999E 01	1.2820000E 04	7.1100000E 03
2	[illegible]	[illegible]	4.8739999E 01	0.	0.
3	[illegible]	[illegible]	4.8759999E 01	0.	0.
4	[illegible]	[illegible]	1.4400000E 02	0.	0.
5	[illegible]	[illegible]	3.0200000E 02	0.	0.
6	[illegible]	[illegible]	7.7875999E 02	0.	0.
7	[illegible]	[illegible]	2.5400000E 03	0.	0.
8	[illegible]	[illegible]	[illegible]	0.	0.
9	[illegible]	[illegible]	3.9500000E 02	0.	0.
10	[illegible]	[illegible]	3.9500000E 02	0.	0.
11	[illegible]	5.0000000E 00	3.2100000E 02	0.	0.
12	[illegible]	[illegible]	6.1370000E 02	0.	0.
13	[illegible]	[illegible]	1.9300000E 02	0.	0.
14	[illegible]	[illegible]	6.8000000E 01	0.	0.
15	[illegible]	[illegible]	4.1799999E 01	0.	0.
16	[illegible]	[illegible]	2.0000000E 01	0.	0.
17	[illegible]	[illegible]	5.4700000E 00	1.8200000E 02	9.6499999E 01
18	[illegible]	1.2375000E 01	3.1200000E-01	1.0500000E 03	5.6500000E 02
19	[illegible]	1.2375000E 00	3.1200000E-01	0.	0.
20	[illegible]	1.2375000E 00	3.1200000E-01	0.	0.
21	[illegible]	4.7500000E 00	2.0000000E 01	1.6500000E 03	8.8000000E 02
22	[illegible]	5.3200000E 00	1.0920000E 02	0.	0.
23	[illegible]	6.1900000E 00	4.5600000E 02	0.	0.
24	2.4[illegible] 02	6.5100000E 00	1.6020000E 03	0.	0.
25	3.3100000E 02	6.2100000E 00	8.3599999E 02	0.	0.
26	2.4630000E 02	4.3300000E 00	1.5540000E 02	0.	0.
27	5.3699999E 01	0.	0.	0.	0.

BEARING STATIONS
3 16 22 27

UNBALANCE ST.	X-UNBALANCE	Y-UNBALANCE
1	1.0000000E 01	0.
10	1.0000000E 01	1.0000000E 01
18	-1.0000000E 01	0.

PEDESTAL DATA,TRANSLATORY MOTION

BRG.STATION	MASS,X-DIR.	KX	CX	MASS,Y-DIR.	KY	CY
3	5.2000E 01	8.2000E 05	2.2000E 01	5.2000E 01	5.3000E 05	2.2000E 01
16	5.2000E 01	4.2000E 05	2.2000E 01	5.2000E 01	5.3000E 05	2.2000E 01
22	4.4000E 01	1.3000E 06	3.4000E 01	4.4000E 01	9.0000E 05	3.4000E 01
27	4.4000E 01	1.3000E 06	3.4000E 01	4.4000E 01	9.0000E 05	3.4000E 01

PEDESTAL DATA,ROTATIONAL MOTION

BRG.STATION	INERTIA,X	MX	DX	INERTIA,Y	MY	DY

3	9.5000E 01	1.7000E 06	1.8000E 01	9.5000E 01	1.3000E 06	1.8000E 01
16	9.5000E 01	1.7000E 06	1.8000E 01	9.5000E 01	1.3000E 06	1.8000E 01
22	8.5000E 01	1.9000E 06	2.7000E 01	8.5000E 01	1.5000E 06	2.7000E 01
27	8.5000E 01	1.9000E 06	2.7000E 01	8.5000E 01	1.5000E 06	2.7000E 01

INITIAL SPEED	FINAL SPEED	SPEED INCR.
1.000000E 03	5.100000E 03	2.000000E 03

BEARING AT STATION NO. 3

KXX	CXX	KXY	CXY	KYY	CYY	KYX	CYX
1.542000E 06	3.362000E 06	-8.010000E 05	1.302000E 06	1.542000E 05	1.040000E 06	9.720000E 05	1.302000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 16

KXX	CXX	KXY	CXY	KYY	CYY	KYX	CYX
1.542000E 05	3.362000E 05	-8.010000E 05	1.302000E 06	1.542000E 05	1.040000E 06	9.720000E 05	1.302000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 22

KXX	CXX	KXY	CXY	KYY	CYY	KYX	CYX
1.463000E 06	3.296000E 05	-1.045000E 06	1.781000E 06	-1.197000E 05	1.754000E 06	1.175000E 06	1.781000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 27

KXX	CXX	KXY	CXY	KYY	CYY	KYX	CYX
1.463000E 05	3.296000E 06	-1.045000E 06	1.781000E 06	-1.197000E 05	1.754000E 06	1.175000E 06	1.781000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 3

MXX	DXX	MXY	DXY	MYY	DYY	MYX	DYX
1.070000E 06	2.240000E 06	-5.700000E 05	9.140000E 05	1.070000E 05	6.800000E 05	6.320000E 05	9.140000E 05
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 16

MXX	DXX	MXY	DXY	MYY	DYY	MYX	DYX
1.070000E 06	2.240000E 06	-5.700000E 05	9.140000E 05	1.070000E 05	6.800000E 05	6.320000E 05	9.140000E 05
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 22

MXX	DXX	MXY	DXY	MYY	DYY	MYX	DYX
9.800000E 05	2.160000E 05	-7.000000E 05	1.330000E 06	-8.700000E 04	1.200000E 06	7.600000E 05	1.330000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 27

MXX	DXX	MXY	DXY	MYY	DYY	MYX	DYX
9.800000E 05	2.160000E 06	-7.000000E 05	1.330000E 06	-8.700000E 04	1.200000E 06	7.600000E 05	1.330000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

ROTOR SPEED= 1.000000E 03RPM
WITHOUT GYROSCOPIC MOMENT

	AMPLITUDE				BENDING MOMENT			
STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
1	1.33225E-01	3.16944E-02	-6.60054E 01	5.63501E 01	0.	0.	0.	0.

2	1.2[illegible]E-01	[illegible]55316E-02	-6.55021E 01	5.77723E 01	6.7643[illegible] 01	6.62211E 01	-6.12255E 01	6.11301E 01
					6.7643[illegible] 01	6.622[illegible] 01	-6.12255E 01	6.11301E 01
3	1.1[illegible]E-01	[illegible]58607E-02	-6.44160E 01	5.96446E 01	1.41730E 02	1.39770E 02	-6.12845E 01	6.11785E 01
					1.41139E 02	1.38330E 02	-5.88327E 01	5.88597E 01
4	1.115[illegible]E-01	2.45263E-02	-6.37640E 01	6.19362E 01	8.28036E 01	6.43807E 01	2.97650E 00	-3.72061E 01
					8.28036E 01	6.43809E 01	2.97650E 00	-3.72061E 01
5	1.0[illegible]E-01	[illegible]44543E-02	-6.25643E 01	6.53146E 01	1.21149E 02	7.84904E 01	-3.48982E 01	-7.61851E 01
					1.21149E 02	7.84904E 01	-3.48982E 01	-7.61851E 01
6	1.015[illegible]E-01	[illegible]45146E-02	-6.22053E 01	6.64794E 01	1.55204E 02	1.04926E 02	-4.01893E 01	-8.14786E 01
					1.55204E 02	1.04926E 02	-4.01893E 01	-8.14786E 01
7	9.[illegible]E-02	[illegible]47797E-02	-6.13255E 01	6.97453E 01	2.49021E 02	1.83541E 02	-4.65524E 01	-8.70926E 01
					2.49021E 02	1.83541E 02	-4.65524E 01	-8.70926E 01
8	9.4[illegible]E-02	[illegible]55549E-02	-6.00306E 01	7.60979E 01	3.90441E 02	3.17171E 02	-5.06407E 01	-8.85[illegible]21E 01
					3.90841E 02	3.17171E 02	-5.08407E 01	-8.85[illegible]21E 01
9	7.7[illegible]E-02	2.61943E-02	-5.[illegible]E 01	8.17383E 01	4.83485E 02	4.13001E 02	-5.29899E 01	-8.80270E 01
					4.83485E 02	4.13001E 02	-5.29899E 01	-8.80270E 01
10	6.[illegible]7414E-02	[illegible]57240E-02	-5.97311E 01	8.99129E 01	5.83796E 02	5.23994E 02	-5.57011E 01	-8.63069E 01
					5.83796E 02	5.23994E 02	-5.57011E 01	-8.63069E 01
11	5.[illegible]E-02	[illegible]33[illegible]E-02	-6.07[illegible]E 01	-8.11221E 01	4.93571E 02	4.36314E 02	-6.02057E 01	-8.52843E 01
					4.93571E 02	4.36314E 02	-6.02057E 01	-8.52843E 01
12	5.[illegible]E-02	[illegible]07219 -02	-6.177[illegible]E 01	-7.2[illegible]E 01	4.13690E 02	3.75773E 02	-6.48833E 01	-8.40181E 01
					4.13690E 02	3.75773E 02	-6.48833E 01	-8.40181E 01
13	4.[illegible]E-02	1.6[illegible]E-02	-6.[illegible]E 01	-5.86551E 01	3.21607E 02	2.97200E 02	-7.56815E 01	-8.00407E 01
					3.21607E 02	2.97200E 02	-7.56815E 01	-8.00407E 01
14	4.1[illegible]E-02	1.36[illegible]E-02	-6.23890E 01	-4.50629E 01	2.58077E 02	2.42209E 02	8.73981E 01	-7.12185E 01
					2.58077E 02	2.42209E 02	8.73981E 01	-7.12185E 01
15	4.[illegible]	1.25369E-02	-6.1[illegible]E 01	-3.80439E 01	2.33730E 02	2.19383E 02	7.51650E 01	-6.38466E 01
					2.33730E 02	2.19383E 02	7.51650E 01	-6.38466E 01
16	4.[illegible]E-02	[illegible]57301E-02	-5.7[illegible]E 01	-2.59448E 01	2.01917E 02	1.87289E 02	5.37639E 01	-5.18581E 01
					2.03680E 02	1.89222E 02	4.94539E 01	-4.71989E 01
17	5.[illegible]E-02	[illegible]14224E-02	-4.4[illegible]E 01	4.49005E 0[illegible]	9.61994E 01	8.57507E 01	5.01761E 01	-4.67364E 01
					9.61994E 01	8.57507E 01	5.01761E 01	-4.67364E 01
18	9.[illegible]E-02	[illegible]06168E-02	-3.91520E 01	2.49925E 01	3.48739E 01	2.92791E 01	-4.41341E 01	3.94060E 01
					3.48739E 01	2.92771E 01	-4.41341E 01	3.94060E 01
19	2.[illegible]E-02	8.16403E-03	-4.39077E 01	2.23748E 01	1.58340E 01	1.33901E 01	-3.98603E 01	3.18357E 01
					1.58340E 01	1.33901E 01	-3.98603E 01	3.18357E 01
20	2.0[illegible]E-02	3.61540E-03	-4.65430E 01	1.93005E 01	2.08993E 01	1.76587E 01	-4.06003E 01	3.31221E 01
					2.08993E 01	1.76587E 01	-4.06003E 01	3.31221E 01
21	1.76[illegible]E-02	1.76517E-03	-4.86944E 01	1.71498E 01	2.59699E 01	2.19276E 01	-4.10441E 01	3.38977E 01
					2.59699E 01	2.19276E 01	-4.10441E 01	3.38977E 01
22	1.3[illegible]E-02	2.23453E-04	-4.97005E 01	1.58029E 01	4.56145E 01	3.83238E 01	-4.17149E 01	3.50966E 01
					4.53677E 01	3.79242E 01	-4.25603E 01	3.58526E 01
23	1.0[illegible]E-02	4.93603E-04	-5.00546E 01	1.53635E 01	3.66675E 01	3.09212E 01	-4.27218E 01	3.61569E 01
					3.66675E 01	3.09212E 01	-4.27218E 01	3.61569E 01
24	6.540[illegible]E-03	[illegible]67977E-04	-5.02008E 01	1.50902E 01	2.67146E 01	2.27731E 01	-4.28661E 01	3.64755E 01
					2.67146E 01	2.27731E 01	-4.28661E 01	3.64755E 01
25	2.62010E-03	[illegible]49228E-05	-5.05399E 01	1.42904E 01	1.65159E 01	1.42015E 01	-4.24773E 01	3.62317E 01
					1.65159E 01	1.42016E 01	-4.24773E 01	3.62317E 01
26	1.10666E-0[illegible]	[illegible]36845E-04	-4.[illegible]786E 01	1.83491E 01	6.91633E 00	6.00935E 00	-4.06567E 01	3.45589E 01
					6.91633E 00	6.00935E 00	-4.06567E 01	3.45589E 01
27	3.690[illegible]E-03	2.54490E-04	-4.99316E 01	1.62866E 01	3.29524E-01	1.77616E-01	3.07324E 01	-2.87460E 01
					1.39003E-02	2.46940E-03	-6.36686E 01	-4.36855E 01

FORCE TRANSMITTED TO BEARING HOUSING

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG.	Y-AMPLITUDE	Y-PHASE ANG
3	3.59537E 01	3.16414E 01	-6.12506E 01	7.45354E 01	3.26896E 01	1.64737E 01	3.50033E 01	1.03069E 01
16	1.49426E 01	1.14576E 01	-9.31556E 00	-5.48398E 01	1.42744E 01	1.17635E 02	1.15424E 01	1.13496E 02
22	5.78336E 00	4.76837E 00	-4.23079E 01	3.59632E 01	5.34777E 00	1.79080E 02	5.25290E 00	1.68132E 02
27	1.55714E 00	1.31863E 00	-4.38735E 01	3.73536E 01	1.44749E 00	-1.79776E 00	1.43815E 00	-1.12727E 01

FORCE TRANSMITTED TO FOUNDATION

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	3.60461E 01	3.17056E 01	-6.14367E 01	7.47195E 01	3.27486E 01	1.64734E 01	3.51012E 01	1.03062E 01
16	1.43688E 01	1.14893E 01	-9.35752E 00	-5.48593E 01	1.43002E 01	1.17634E 02	1.15747E 01	1.13496E 02
22	5.79066E 00	4.77407E 00	-4.23719E 01	3.60258E 01	5.35291E 00	1.79080E 02	5.26021E 00	1.68132E 02
27	1.55896E 00	1.32019E 00	-4.39478E 01	3.74267E 01	1.44888E 00	-1.79791E 00	1.44015E 00	-1.12731E 01

PEDESTAL MOTION

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	6.64499E-02	3.95668E-02	-8.41662E 01	-8.34243E 01	3.99372E-02	1.63124E 01	6.62280E-02	1.00572E 01
16	2.19403E-02	1.73113E-02	-8.10013E 01	1.61245E 01	1.74392E-02	1.17473E 02	2.18388E-02	1.13247E 02
22	5.94239E-03	3.97523E-03	-7.59349E 01	6.83912E 01	4.11761E-03	1.78923E 02	5.84463E-03	1.67905E 02
27	1.61951E-03	1.03575E-03	-7.79186E 01	7.03357E 01	1.11452E-03	-1.95483E 00	1.60015E-03	-1.14997E 01

ENERGY INPUT= 5.7557180E-03 ENERGY DISSIPATED= 5.6887764E-03

ITERAT.NO.	ERROR
1	9.9999996E-01
2	1.5306809E-06

WITH GYROSCOPIC MOMENT

	AMPLITUDE				BENDING MOMENT			
STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
1	1.33219E-01	5.16725E-02	-6.60012E 01	5.63507E 01	0.	0.	0.	0.
					2.95442E-01	5.62438E-02	2.12195E 01	-5.58859E 01
2	1.25491E-01	2.35193E-02	-6.54994E 01	5.77229E 01	6.76126E 01	6.65619E 01	-5.90063E 01	5.89962E 01
					6.76126E 01	6.65619E 01	-5.90063E 01	5.89962E 01
3	1.16734E-01	2.58758E-02	-6.49147E 01	5.94451E 01	1.41699E 02	1.39511E 02	-6.02130E 01	6.01479E 01
					1.41111E 02	1.38071E 02	-5.82349E 01	5.83030E 01
4	1.11553E-01	2.45266E-02	-6.37690E 01	6.19866E 01	8.25553E 01	6.43095E 01	2.76741E 00	-3.69937E 01
					8.25553E 01	6.43095E 01	2.76741E 00	-3.69937E 01
5	1.04053E-01	2.44568E-02	-6.25653E 01	6.53150E 01	1.21028E 02	7.85333E 01	-3.50179E 01	-7.61433E 01
					1.21028E 02	7.85333E 01	-3.50179E 01	-7.61433E 01
6	1.01557E-01	2.45215E-02	-6.22065E 01	6.64799E 01	1.55110E 02	1.04991E 02	-4.02851E 01	-8.14418E 01
					1.55110E 02	1.04991E 02	-4.02851E 01	-8.14418E 01
7	9.50768E-02	2.47621E-02	-6.13274E 01	6.97459E 01	2.48958E 02	1.83671E 02	-4.66154E 01	-8.70610E 01
					2.48958E 02	1.83671E 02	-4.66154E 01	-8.70610E 01
8	8.49841E-02	2.55585E-02	-6.00838E 01	7.60989E 01	3.90793E 02	3.17236E 02	-5.08852E 01	-8.85622E 01
					3.90793E 02	3.17236E 02	-5.08852E 01	-8.85622E 01
9	7.77260E-02	2.61977E-02	-5.95358E 01	8.17399E 01	4.83442E 02	4.13048E 02	-5.30290E 01	-8.79970E 01
					4.83442E 02	4.13048E 02	-5.30290E 01	-8.79970E 01
10	6.87373E-02	2.57265E-02	-5.97373E 01	8.99157E 01	5.83758E 02	5.24018E 02	-5.57373E 01	-8.62756E 01
					5.83758E 02	5.24018E 02	-5.57373E 01	-8.62756E 01
11	5.98267E-02	2.33900E-02	-6.07674E 01	-8.11178E 01	4.83537E 02	4.36319E 02	-6.02414E 01	-8.52522E 01
					4.83537E 02	4.36319E 02	-6.02414E 01	-8.52522E 01
12	5.33284E-02	2.07220E-02	-6.17842E 01	-7.29509E 01	4.13458E 02	3.75764E 02	-6.49180E 01	-8.39857E 01
					4.13458E 02	3.75764E 02	-6.49180E 01	-8.39857E 01
13	4.96877E-02	1.65968E-02	-6.28591E 01	-5.86486E 01	3.21574E 02	2.97171E 02	-7.57111E 01	-8.00117E 01
					3.21574E 02	2.97171E 02	-7.57111E 01	-8.00117E 01
14	4.16839E-02	1.36521E-02	-6.23982E 01	-4.50560E 01	2.58032E 02	2.42166E 02	8.73888E 01	-7.12086E 01
					2.58032E 02	2.42166E 02	8.73888E 01	-7.12086E 01
15	4.05512E-02	1.25318E-02	-6.13393E 01	-3.80772E 01	2.33186E 02	2.19336E 02	7.51740E 01	-6.38547E 01
					2.33186E 02	2.19336E 02	7.51740E 01	-6.38547E 01
16	4.00520E-02	1.15693E-02	-5.78879E 01	-2.59426E 01	2.01758E 02	1.87240E 02	5.37863E 01	-5.18803E 01
					2.03620E 02	1.89174E 02	4.94734E 01	-4.72180E 01
17	5.26791E-02	2.14154E-02	-4.48027E 01	4.49430E 00	9.61293E 01	8.56921E 01	5.02037E 01	-4.67634E 01
					9.61404E 01	8.57003E 01	5.01989E 01	-4.67585E 01
18	9.55543E-02	6.05909E-02	-3.93608E 01	2.39970E 01	3.49361E 01	2.93494E 01	-4.40823E 01	3.93722E 01
					3.48604E 01	2.92649E 01	-4.41419E 01	3.94084E 01
19	2.65246E-02	8.15440E-03	-4.39194E 01	2.23345E 01	1.58295E 01	1.33868E 01	-3.98549E 01	3.18225E 01
					1.58295E 01	1.33868E 01	-3.98549E 01	3.18225E 01
20	2.04058E-02	3.60398E-03	-4.65548E 01	1.93087E 01	2.08930E 01	1.76536E 01	-4.05980E 01	3.31122E 01
					2.08930E 01	1.76536E 01	-4.05980E 01	3.31122E 01

21	1.74926E-02	1.75583E-03	-4.45063E 01	1.71569E 01	2.5961[illegible] 01	2.19[illegible] 01	-4.10634E 01	3.38597E 01
					2.59643E 01	2.18034E 01	-4.14600E 01	3.43700E 01
22	1.3[illegible]E-02	[illegible].18336E-04	-4.97077E 01	1.54028E 01	4.55871E 01	3.81[illegible] 01	-4.1[illegible]475E 01	3.53576E 01
					4.53412E 01	3.77923E 01	-4.27[illegible] 01	3.60773E 01
23	1.0[illegible]24E-02	[illegible].90662E-04	-5.00614E 01	1.53604E 01	3.66464E 01	3.08166E 01	-4.29427E 01	3.64086E 01
					3.66464E 01	3.08166E 01	-4.29427E 01	3.64086E 01
24	6.[illegible]E-03	[illegible].67245E-04	-5.02029E 01	1.50430E 01	2.67000E 01	2.26377E 01	-4.30975E 01	3.67446E 01
					2.67000E 01	2.26377E 01	-4.30975E 01	3.67446E 01
25	2.[illegible]E-03	[illegible].56760E-05	-5.05276E 01	1.42600E 01	1.65084E 01	1.41619E 01	-4.28132E 01	3.66075E 01
					1.65084E 01	1.41619E 01	-4.28132E 01	3.66075E 01
26	1.[illegible]E-03	[illegible].34824E-04	-4.[illegible]E 01	1.84646E 01	6.32498E 00	6.01373E 00	-4.06290E 01	3.46222E 01
					6.32386E 00	6.01373E 00	-4.06290E 01	3.46222E 01
27	3.[illegible]E-03	[illegible].55858E-04	-4.99774E 01	1.63368E 01	3.46817E-01	1.90433E-01	3.70436E 01	-2.91556E 01
					2.73015E-02	7.36452E-03	8.82851E 01	-5.81188E 01

FORCE TRANSMITTED TO BEARING HOUSING

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	3.[illegible] 01	[illegible].16373E 01	-6.12307E 01	7.45266E 01	3.76875E 01	1.64797E 01	3.50010E 01	1.03073E 01
16	1.4[illegible] 01	1.14572E 01	-9.33[illegible]E 00	-5.48[illegible]E 01	1.42704E 01	1.17635E 02	1.15422E 01	1.13492E 02
22	5.75124E 00	4.76175E 00	-4.23617E 01	3.60209E 01	5.34254E 00	1.79111E 02	5.24921E 00	1.68110E 02
27	1.5[illegible]	[illegible].31556E 00	-4.4[illegible]E 01	3.75770E 01	1.44512E 00	-1.67470E 00	1.43700E 00	-1.12612E 01

FORCE TRANSMITTED TO FOUNDATION

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	3.[illegible] 01	3.17[illegible]20E 01	-6.14244E 01	7.47107E 01	3.27465E 01	1.64794E 01	3.50988E 01	1.03066E 01
16	1.4[illegible] 01	[illegible].14859E 01	-9.37475E 00	-5.48359E 01	1.42961E 01	1.17655E 02	1.15745E 01	1.13492E 02
22	5.7[illegible]E 00	4.76744E 00	-4.24255E 01	3.60832E 01	5.34766E 00	1.79111E 02	5.25651E 00	1.68110E 02
27	1.[illegible]	[illegible].31709E 00	-4.41056E 01	3.76493E 01	1.44651E 00	-1.67486E 00	1.43900E 00	-1.12615E 01

PEDESTAL MOTION

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	[illegible]E-02	5.95636 -02	-8.51611E 01	-8.34268E 01	3.99346E-02	1.63184E 01	6.62236E-02	1.00576E 01
16	2.1[illegible]E-02	[illegible].73062E-02	-8.10020E 01	1.61270E 02	1.74343E-02	1.17474E 02	2.18385E-02	1.13243E 02
22	5.9[illegible]E-03	[illegible].77010E-03	-7.54877E 01	6.83430E 01	4.11356E-03	1.78954E 02	5.84052E-03	1.67883E 02
27	1.61[illegible]E-03	[illegible].08337E-03	-7.78212E 01	7.02935E 01	1.11269E-03	-1.83178E 00	1.59888E-03	-1.14882E 01

ENERGY INPUT= 5.7[illegible]50025E-03 ENERGY DISSIPATED= 5.6882241E-03

ROTOR SPEED= [illegible] RPM
WITHOUT GYROSCOPIC MOMENT

	AMPLITUDE				BENDING MOMENT			
STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
1	1.4[illegible] 00	8.28899E-01	7.72963E 01	1.97920E 01	0.	0.	0.	0.
					0.	-0.	0.	0.
2	1.43667E 00	[illegible].97325E-01	6.57896E 01	2.69451E 01	6.36295E 02	5.93090E 02	-6.50512E 01	5.74445E 01
					6.36295E 02	5.93090E 02	-6.50512E 01	5.74445E 01
3	1.49[illegible] 00	9.42617E-01	5.28262E 01	3.58313E 01	1.34098E 03	1.23914E 03	-6.67085E 01	5.79608E 01
					1.34024E 03	1.23617E 03	-8.03343E 01	7.03222E 01
4	1.62357E 00	9.53306E-01	3.99008E 01	4.48777E 01	5.54724E 03	1.86739E 03	1.10310E 01	5.03505E 01
					5.54724E 03	1.86739E 03	1.10310E 01	5.03505E 01
5	1.75572E 00	9.04685E-01	3.03957E 01	5.09711E 01	1.17965E 04	3.59872E 03	1.64659E 01	5.54995E 01
					1.17965E 04	3.59872E 03	1.64659E 01	5.54995E 01
6	1.76793E 00	[illegible].77968E-01	2.30910E 01	5.22589E 01	1.38222E 04	4.14637E 03	1.71161E 01	5.62265E 01
					1.38222E 04	4.14637E 03	1.71161E 01	5.62265E 01
7	1.86120E 00	7.97000E-01	2.31072E 01	5.46366E 01	1.81386E 04	5.08695E 03	1.77230E 01	5.75547E 01
					1.81386E 04	5.08695E 03	1.77230E 01	5.75547E 01
8	1.97053E 00	6.47305E-01	1.68099E 01	5.65787E 01	2.12391E 04	4.89721E 03	1.76055E 01	5.93242E 01
					2.12391E 04	4.89721E 03	1.76055E 01	5.93242E 01
9	2.03255E 00	5.29588E-01	1.30000E 01	5.70149E 01	2.07219E 04	3.84040E 03	1.78038E 01	6.08132E 01
					2.07219E 04	3.84040E 03	1.78038E 01	6.08132E 01
10	2.03517E 00	3.78019E-01	8.59501E 00	5.66834E 01	1.76222E 04	1.96381E 03	1.31046E 01	6.35992E 01

					1.76222E 04	1.96381E 03	1.91046E 01	6.35992E 01
11	1.96848E 00	2.47918E-01	4.38656E 00	5.56149E 01	1.46900E 04	1.42724E 03	1.86463E 01	6.43530E 01
					1.46900E 04	1.42724E 03	1.86463E 01	6.43530E 01
12	1.89207E 00	1.60796E-01	8.81326E-01	5.43186E 01	1.20914E 04	1.00510E 03	1.89022E 01	6.55425E 01
					1.20914E 04	1.00510E 03	1.89022E 01	6.55425E 01
13	1.77659E 00	5.74777E-02	-4.77449E 00	5.17134E 01	7.79880E 03	4.62332E 02	2.18334E 01	6.98958E 01
					7.79880E 03	4.62332E 02	2.18334E 01	6.98958E 01
14	1.69206E 00	-2.21752E-03	-9.92946E 00	4.89475E 01	4.26433E 03	3.45195E 02	3.20603E 01	8.16468E 01
					4.26433E 03	3.45195E 02	3.20603E 01	8.16468E 01
15	1.65625E 00	-2.02802E-02	-1.25796E 01	4.74133E 01	2.95271E 03	6.00610E 02	4.29908E 01	-8.56408E 01
					2.95271E 03	6.00610E 02	4.29908E 01	-8.56408E 01
16	1.61116E 00	-2.95271E-02	-1.71408E 01	4.46288E 01	1.99050E 03	1.81107E 03	1.61693E 01	-1.11540E 01
					2.01811E 03	1.82421E 03	2.24614E 01	-1.82973E 01
17	1.64157E 00	8.87774E-02	-2.86498E 01	3.73073E 01	9.45668E 02	7.28762E 02	4.13734E 01	-3.42802E 01
					9.45668E 02	7.28762E 02	4.13734E 01	-3.42802E 01
18	1.90117E 00	4.68199E-01	-3.79674E 01	3.23251E 01	4.97095E 02	2.77480E 02	-4.81562E 01	3.78339E 01
					4.97095E 02	2.77480E 02	-4.81562E 01	3.78339E 01
19	4.64756E-01	1.86537E-02	-4.37875E 01	1.47369E 01	2.78231E 02	1.27910E 02	-4.25849E 01	3.89636E 01
					2.78231E 02	1.27910E 02	-4.25849E 01	3.89636E 01
20	3.67184E-01	-1.88275E-02	-4.67940E 01	8.02847E 00	3.56087E 02	1.68274E 02	-4.33173E 01	3.86775E 01
					3.56087E 02	1.68274E 02	-4.33173E 01	3.86775E 01
21	3.21191E-01	-3.18126E-02	-4.99735E 01	5.10709E 00	4.34432E 02	2.08651E 02	-4.37697E 01	3.84635E 01
					4.34432E 02	2.08651E 02	-4.37697E 01	3.84635E 01
22	2.55896E-01	-3.22043E-02	-5.01592E 01	2.46971E 00	7.61319E 02	3.59911E 02	-4.38876E 01	3.65058E 01
					7.57466E 02	3.55614E 02	-4.40788E 01	3.66401E 01
23	1.95971E-01	-2.70402E-02	-5.04217E 01	6.59812E-01	5.75793E 02	3.00170E 02	-4.67866E 01	4.16216E 01
					5.75793E 02	3.00170E 02	-4.67866E 01	4.16216E 01
24	1.29124E-01	-1.99089E-02	-5.04148E 01	-2.41954E 00	3.93159E 02	2.27362E 02	-5.25277E 01	5.04006E 01
					3.93159E 02	2.27362E 02	-5.25277E 01	5.04006E 01
25	6.05944E-02	-1.23844E-02	-5.08338E 01	-1.27457E 01	2.39305E 02	1.42196E 02	-5.83459E 01	5.84315E 01
					2.39305E 02	1.42196E 02	-5.83459E 01	5.84315E 01
26	2.26099E-02	-1.83292E-03	-6.51812E 01	6.79911E 01	1.04249E 02	6.08142E 01	-5.86858E 01	5.88241E 01
					1.04249E 02	6.08142E 01	-5.86858E 01	5.88241E 01
27	5.99291E-02	-2.64682E-03	-5.44395E 01	2.48664E 01	4.67523E 00	3.01456E 00	1.05980E 01	-9.20085E 00
					8.75587E-01	5.10818E-01	6.99184E 01	-2.99474E 01

FORCE TRANSMITTED TO BEARING HOUSING

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.04706E 03	3.44396E 02	2.95798E 01	6.59514E 01	9.26332E 02	-1.03473E 02	5.97377E 02	-5.41396E 01
16	9.43342E 02	1.61250E 02	2.55023E 00	4.98750E 01	9.42435E 02	-1.29689E 02	1.66469E 02	-1.15521E 02
22	1.05837E 02	4.16590E 01	-4.21140E 01	2.97761E 01	8.33337E 01	-1.69811E 02	7.74113E 01	1.43305E 02
27	2.42550E 01	1.31212E 01	-5.81267E 01	5.76618E 01	1.69764E 01	1.66383E 01	2.17315E 01	-1.37465E 01

FORCE TRANSMITTED TO FOUNDATION

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.06666E 03	3.52560E 02	2.98556E 01	6.57762E 01	9.41596E 02	-1.03481E 02	6.12743E 02	-5.41588E 01
16	9.59902E 02	1.65403E 02	2.57281E 00	4.98592E 01	9.57964E 02	-1.29697E 02	1.70751E 02	-1.15540E 02
22	1.06950E 02	4.21081E 01	-4.22656E 01	2.98733E 01	8.40610E 01	-1.69815E 02	7.83909E 01	1.43296E 02
27	2.45159E 01	1.32492E 01	-5.83071E 01	5.78059E 01	1.71246E 01	1.66342E 01	2.20069E 01	-1.37551E 01

PEDESTAL MOTION

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.52648E 00	5.69827E-01	4.52559E 01	5.53972E 01	1.14825E 00	-1.03964E 02	1.15602E 00	-5.49060E 01
16	1.17996E 00	3.11985E-01	4.07808E 00	4.87321E 01	1.16821E 00	-1.30130E 02	3.22144E-01	-1.16287E 02
22	1.01715E-01	3.76905E-02	-5.62118E 01	3.86904E 01	6.46601E-02	-1.70286E 02	8.70949E-02	1.42616E 02
27	2.55691E-02	1.08420E-02	-7.11528E 01	6.73291E 01	1.31723E-02	1.61634E 01	2.44503E-02	-1.44351E 01

ENERGY INPUT= 1.8328001E 00   ENERGY DISSIPATED= 1.7368715E 00

ITERAT.NO.	ERROR
1	1.0000000E 00

2 1.0567562E-02
3 4.6740172E-06
WITH GYROSCOPIC MOMENT

AMPLITUDE

STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
1	1.41880E 00	6.16224E-01	7.74191E 01	2.00515E 01
2	1.43311E 00	6.85137E-01	6.55977E 01	2.70899E 01
3	1.49402E 00	9.30981E-01	5.29604E 01	3.58428E 01
4	1.61860E 00	9.42627E-01	4.00539E 01	4.47830E 01
5	1.74367E 00	8.95572E-01	3.05101E 01	5.08447E 01
6	1.78157E 00	8.67443E-01	2.81994E 01	5.21326E 01
7	1.85416E 00	7.90045E-01	2.31694E 01	5.45200E 01
8	1.96280E 00	6.42927E-01	1.67947E 01	5.64856E 01
9	2.02461E 00	5.27127E-01	1.29344E 01	5.69373E 01
10	2.02741E 00	3.74073E-01	8.47774E 00	5.66244E 01
11	1.96123E 00	2.50305E-01	4.23160E 00	5.55771E 01
12	1.88553E 00	1.64886E-01	7.04103E-01	5.43032E 01
13	1.77060E 00	6.37659E-02	-4.47211E 00	5.17440E 01
14	1.68654E 00	5.58863E-03	-1.01246E 01	4.90318E 01
15	1.65043E 00	-1.14911E-02	-1.27752E 01	4.75303E 01
16	1.60557E 00	-2.03715E-02	-1.73198E 01	4.48111E 01
17	1.63215E 00	9.86370E-02	-2.87692E 01	3.76995E 01
18	1.87752E 00	4.95703E-01	-3.81407E 01	3.29932E 01
19	3.96374E-01	2.73252E-02	-4.30360E 01	1.71375E 01
20	3.00483E-01	-1.10280E-02	-4.60149E 01	1.08072E 01
21	2.60354E-01	-2.41938E-02	-4.84226E 01	6.63529E 00
22	2.18792E-01	-2.52861E-02	-4.95615E 01	3.89348E 00
23	1.75572E-01	-2.30718E-02	-4.98318E 01	1.27652E 00
24	1.26560E-01	-1.97946E-02	-5.00081E 01	-3.32986E 00
25	7.70173E-02	-1.62777E-02	-5.11655E 01	-1.44605E 01
26	3.97652E-02	-1.09632E-02	-6.09969E 01	-5.26642E 01
27	3.98971E-02	-2.30634E-03	-6.59563E 01	7.53107E 01

BENDING MOMENT

MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
0.	0.	0.	0.
9.09622E 01	-2.91400E 00	-1.40873E 01	4.40262E 01
7.10322E 02	5.90796E 02	-4.13301E 01	3.61481E 01
7.10322E 02	5.90796E 02	-4.13301E 01	3.61481E 01
1.40907E 03	1.24310E 03	-5.03870E 01	4.29008E 01
1.39225E 03	1.25367E 03	-5.83011E 01	4.95766E 01
5.60510E 03	1.84727E 03	1.05873E 01	5.02715E 01
5.60510E 03	1.84747E 03	1.05873E 01	5.02715E 01
1.18149E 04	3.55340E 03	1.62434E 01	5.53833E 01
1.18149E 04	3.55340E 03	1.62434E 01	5.53833E 01
1.38287E 04	4.09408E 03	1.69268E 01	5.61109E 01
1.38287E 04	4.09408E 03	1.69268E 01	5.61109E 01
1.81191E 04	5.02198E 03	1.75775E 01	5.74407E 01
1.81191E 04	5.02198E 03	1.75775E 01	5.74407E 01
2.11933E 04	4.82684E 03	1.74707E 01	5.92104E 01
2.11933E 04	4.82684E 03	1.74707E 01	5.92104E 01
2.06675E 04	3.77190E 03	1.76593E 01	6.06969E 01
2.06675E 04	3.77190E 03	1.76593E 01	6.06969E 01
1.75663E 04	1.89932E 03	1.89369E 01	6.34753E 01
1.75663E 04	1.89932E 03	1.89369E 01	6.34753E 01
1.46432E 04	1.36971E 03	1.84511E 01	6.42191E 01
1.46432E 04	1.36971E 03	1.84511E 01	6.42191E 01
1.20526E 04	9.51110E 02	1.86796E 01	6.53965E 01
1.20526E 04	9.51110E 02	1.86796E 01	6.53965E 01
7.77213E 03	4.08677E 02	2.15565E 01	6.97237E 01
7.77213E 03	4.08677E 02	2.15565E 01	6.97237E 01
4.24493E 03	2.85020E 02	3.18022E 01	8.15297E 01
4.24493E 03	2.85020E 02	3.18022E 01	8.15297E 01
2.93790E 03	5.38269E 02	4.29223E 01	-8.55498E 01
2.93790E 03	5.38269E 02	4.29223E 01	-8.55498E 01
1.96809E 03	1.78693E 03	2.57296E 01	-2.00133E 01
2.00117E 03	1.79345E 03	3.08262E 01	-2.59742E 01
9.40464E 02	7.00830E 02	4.49218E 01	-3.67152E 01
9.41268E 02	7.01308E 02	4.48762E 01	-3.67146E 01
5.09853E 02	2.85633E 02	-4.80058E 01	3.72168E 01
5.06594E 02	2.75465E 02	-4.78146E 01	3.71391E 01
2.93162E 02	1.26544E 02	-4.22147E 01	3.72098E 01
2.93162E 02	1.26544E 02	-4.22147E 01	3.72098E 01
3.73432E 02	1.66664E 02	-4.29210E 01	3.70747E 01
3.73432E 02	1.66664E 02	-4.29210E 01	3.70747E 01
4.54114E 02	2.06791E 02	-4.33700E 01	3.69724E 01
1.78069E 02	4.63885E 01	8.48563E 01	-3.19987E 01
3.40578E 02	2.77384E 02	-5.11552E 01	5.97563E 01
3.38102E 02	2.73565E 02	-5.17224E 01	6.03564E 01
2.74284E 02	2.06059E 02	-8.26474E 01	-8.35092E 01
2.74284E 02	2.06059E 02	-8.26474E 01	-8.35092E 01
2.26572E 02	1.17612E 02	8.88393E 01	-6.77249E 01
2.26572E 02	1.17612E 02	8.88393E 01	-6.77249E 01
1.60784E 02	5.70047E 01	-8.99297E 01	-6.30735E 01
1.60784E 02	5.70047E 01	-8.99297E 01	-6.30735E 01
7.42689E 01	2.31675E 01	-8.80950E 01	-6.37452E 01
7.42689E 01	2.31675E 01	-8.80950E 01	-6.37452E 01
4.25533E 00	2.66069E 00	1.65911E 01	-1.07215E 01
1.14900E 00	5.30268E-01	6.12956E 01	-2.34527E 01

FORCE TRANSMITTED TO BEARING HOUSING

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.04156E 03	3.40752E 02	2.96853E 01	6.59008E 01	9.20447E 02	-1.03535E 02	5.94721E 02	-5.39515E 01
16	9.39260E 02	1.63854E 02	2.51802E 00	4.98642E 01	9.38381E 02	-1.29696E 02	1.68817E 02	-1.15987E 02
22	9.11682E 01	3.83229E 01	-4.07305E 01	3.01590E 01	7.34723E 01	-1.69739E 02	6.61976E 01	1.46180E 02
27	1.71145E 01	4.71367E 00	-8.55446E 01	-6.53920E 01	4.88388E 00	4.04048E 01	1.70667E 01	2.58374E 01

FORCE TRANSMITTED TO FOUNDATION

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.06104E 03	3.48826E 02	2.99610E 01	6.57263E 01	9.35614E 02	-1.03543E 02	6.10018E 02	-5.39707E 01
16	9.54752E 02	1.68074E 02	2.54031E 00	4.98483E 01	9.53843E 02	-1.29704E 02	1.73159E 02	-1.16006E 02
22	9.21152E 01	3.87400E 01	-4.09883E 01	3.02656E 01	7.41135E 01	-1.69743E 02	6.70353E 01	1.46171E 02
27	1.73307E 01	4.75482E 00	-8.55632E 01	-6.53907E 01	4.92650E 00	4.04007E 01	1.72827E 01	2.58208E 01

PEDESTAL MOTION

BRG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.51949E 00	5.63435E-01	4.53273E 01	5.54148E 01	1.14095E 00	-1.04026E 02	1.15088E 00	-5.47178E 01
16	1.16585E 00	3.17022E-01	4.03175E 00	4.87149E 01	1.16318E 00	-1.30187E 02	3.26688E-01	-1.16754E 02
22	8.70535E-02	3.49097E-02	-5.55668E 01	4.01300E 01	5.70085E-02	-1.70214E 02	7.44784E-02	1.45491E 02
27	1.92768E-02	3.65928E-03	-8.70092E 01	-6.54209E 01	3.78949E-03	3.99299E 01	1.92016E-02	2.51489E 01

ENERGY INPUT= 1.8061321E 00 ENERGY DISSIPATED= 1.7106469E 00

ROTOR SPEED= 5.0000000E 03RPM
WITHOUT GYROSCOPIC MOMENT

	AMPLITUDE				BENDING MOMENT			
STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE
1	3.30049E 00	-9.78419E-01	-1.32549E 01	-5.42544E 01	0.	0.	0.	0.
					0.	-0.	0.	0.
2	3.01417E 00	-6.95441E-01	-1.59324E 01	-5.71460E 01	2.20063E 03	1.33456E 03	1.69728E 01	-2.40267E 01
					2.20063E 03	1.33456E 03	1.69728E 01	-2.40267E 01
3	2.72622E 00	-7.39853E-01	-1.[illegible]270E 01	-6.04243E 01	4.74952E 03	2.69587E 03	1.65225E 01	-2.45024E 01
					4.66506E 03	2.69327E 03	1.66070E 01	-2.47640E 01
4	2.38254E 00	-6.34830E-01	-2.18864E 01	-6.38258E 01	5.82459E 03	1.93310E 03	-5.05905E 01	7.96635E 01
					5.82459E 03	1.93310E 03	-5.05905E 01	7.96635E 01
5	1.91930E 00	-4.26958E-01	-2.44890E 01	-6.70658E 01	1.00786E 04	6.59499E 02	-3.82120E 01	-8.72450E 01
					1.00786E 04	6.59499E 02	-3.82120E 01	-8.72450E 01
6	1.74907E 00	-3.54102E-01	-2.53557E 01	-6.81960E 01	1.13190E 04	4.82850E 02	-3.57626E 01	-8.49849E 01
					1.13190E 04	4.82850E 02	-3.57626E 01	-8.49849E 01
7	1.29200E 00	-1.57951E-01	-2.80978E 01	-7.19878E 01	1.19921E 04	7.75460E 02	-3.16886E 01	-8.32437E 01
					1.19921E 04	7.75460E 02	-3.16886E 01	-8.32437E 01
8	5.49721E-01	1.92874E-01	-3.32819E 01	-8.70355E 01	5.72771E 03	2.07235E 03	-1.51953E 01	8.18128E 01
					5.72771E 03	2.07235E 03	-1.51953E 01	8.18128E 01
9	5.22524E-01	5.24449E-02	3.03470E 01	-9.11565E-01	3.36099E 03	-1.99087E 03	5.35735E 01	3.94613E 01
					3.36099E 03	-1.99087E 03	5.35735E 01	3.94613E 01
10	1.03959E 00	-3.68454E-01	1.28288E 01	-2.52928E 01	1.04294E 04	-1.84785E 03	-4.97633E 01	-8.08463E 01
					1.04294E 04	-1.84785E 03	-4.97633E 01	-8.08463E 01
11	1.54208E 00	-6.03922E-01	4.40389E 00	-3.51665E 01	1.17126E 04	-3.36584E 03	-4.76338E 01	-8.21824E 01
					1.17126E 04	-3.36584E 03	-4.76338E 01	-8.21824E 01
12	1.88847E 00	-7.30927E-01	1.64330E 00	-3.85498E 01	1.17993E 04	-3.46333E 03	-4.93346E 01	-8.52324E 01
					1.17993E 04	-3.46333E 03	-4.93346E 01	-8.52324E 01
13	2.33540E 00	-8.71261E-01	-2.04422E-01	-4.10064E 01	1.03863E 04	-1.44265E 03	-5.70955E 01	6.60702E 01
					1.03863E 04	-1.44265E 03	-5.70955E 01	8.60702E 01
14	2.65530E 00	-9.53062E-01	-7.03255E-01	-4.18654E 01	8.26053E 03	2.41842E 03	-6.61718E 01	7.75497E 01
					8.26053E 03	2.41842E 03	-6.61718E 01	7.75497E 01
15	2.79527E 00	-9.76999E-01	-6.06268E-01	-4.19176E 01	7.30113E 03	4.52177E 03	-7.03681E 01	7.51735E 01
					7.30113E 03	4.52177E 03	-7.03681E 01	7.51735E 01
16	3.02327E 00	-9.84058E-01	2.04705E-01	-4.13302E 01	7.98150E 03	5.88373E 03	1.98928E 01	-2.30785E 01
					8.07710E 03	5.89325E 03	1.98314E 01	-2.29569E 01
17	3.85196E 00	-7.73619E-01	5.04407E 00	-3.69519E 01	3.27980E 03	3.07904E 03	2.27755E 01	-2.32504E 01
					3.27980E 03	3.07904E 03	2.27755E 01	-2.32504E 01
18	5.39252E 00	6.79483E-02	1.07702E 01	-3.16596E 01	1.70337E 03	3.92992E 02	1.43140E 01	-2.78849E 01

INPUT FOR PN0011:

UNBALANCE RESPONSE OF A FLEXIBLE ROTOR IN FLEXIBLE, DAMPED BEARINGS

Card 1 Text Col. 2-72

Card 2 Text Col. 2-72

Card 3 (10I5)

______ 1. NS. Number of rotor mass stations (≤ 80)

______ 2. NB. Number of bearings (≤ 25)

______ 3. NU. Number of unbalance stations (≤ 80)

______ 4. NC. Number of coupling stations (≤ 20)

______ 5. NPST. 0: Rigid Pedestal 1: Flexible Pedestal

______ 6. NMOM. 0: No bearing resistance to moment 1: Moment resistance i

______ 7. NGYR. 0: No gyroscopic moment 1: Gyroscopic moment calculation

______ 8. NCAL. 1: 1st type of bearing data input ≥ 2: 2nd type of beari data input.

______ 9. 0: no diagnostic 1: diagnostic given

______ 10. 0: More input follows 1: last set of input

Card 4 (1P4E15.7)

____________________ 1. E, Youngs modulus, lbs/in^2

____________________ 2. Scale factor in simultaneous equation soluti

IF NGYR = 1

Card (I5, 1PE23.6)

________ 1. NIT. Number of iterations in gyroscopic mom.

____________________ 2. Convergence limit for gyroscopic moment calc

ROTOR DATA

If NGYR = 0, use only first 3 columns, FORMAT (1P3E14.6)

If NGYR = 1, use all 5 columns, FORMAT (1P5E14.6)

Give one card for each rotor station, in total NS cards

Rotor Station (don't punch)	Station Mass lbs.	Length of shaft section inch	Cross sectional Moment of Inertia in^4	Polar Mass Moment of Inertia $lbs.in^2$	Transverse Mass Moment of Inertia $lbs.in^2$
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Rotor Stations with Bearing Support

(14I5)

Give NB items

Unbalance Data
(I5,1P2E15.7)

Give one card for each rotor station with unbalance, in total NU cards

__________.1. Rotor station number

____________________.2. X-component of unbalance, oz.inch

____________________.3. Y-component of unbalance, oz.inch

Rotor Stations with Coupling

(14I5)

Applies only if NC ≠ 0. Give NC items.

Pedestal Data for Translatory Motion

(1P6E12.4)

Applies only when NPST = 1. Give one card for each bearing, in total NB card

Pedes.Mass x-direction lbs.	Pedes.Stiffn x-direction lbs/in	Pedes.Damping x-direction lbs.sec/in	Pedes.Mass y-directic lbs.	Pedes.Stiffn. y-direction lbs/in	Pedes.D y-direc lbs.se

Pedestal Data for Tilting

(1P6E12.4)

Applies only when NPST = 1 and NMOM = 1. Give on card for each bearing, in total NB cards.

Mass Mom. of Inert. x-direction $lbs.in^2$	Angular Stiffn. x-direction lbs.in/rad	Angular Damping x-direction lbs.in.sec/rad	Mass Mom. of Inert. y-direction $lbs.in^2$	Angular Stiffn. y-direction lbs.in/rad	Angular Damping y-directi lbs.in.se

Type 1 Bearing Data, NCAL = 1

Speed Data (1P3E14.6)

____________________ 1. Initial speed, RPM

____________________ 2. Final speed, RPM

____________________ 3. Speed increment, RPM

Bearing Coefficients for Translatory Motion

(1P3E14.6)

Give 8 cards per bearing, in total 8•NB cards. Each card gives one coefficient in the form: $K_{xx} = K_{xx,o} + K_{xx,1}\omega + K_{xx,2}\omega^2$, $\omega C_{xx} = C_{xx,o} + C_{xx,1}\omega + C_{xx,2}\omega^2$, etc.

			K_{xx}
			ωC_{xx}
			K_{xy}
			ωC_{xy}
			K_{yy}
			ωC_{yy}
			K_{yx}
			ωC_{yx}

			K_{xx}
			ωC_{xx}
			K_{xy}
			ωC_{xy}
			K_{yy}
			ωC_{yy}
			K_{yx}
			ωC_{yx}

Bearing Coefficients for Tilting

(1P3E14.6)

Applies only when NMOM = 1. Give 8 cards per bearing, in total 8•NB cards. Each card gives one coefficient in the form:

$$M_{xx} = M_{xx,o} + M_{xx,1}\omega + M_{xx,2}\omega^2, \quad \omega D_{xy} = D_{xx,o} + D_{xx,1}\omega + D_{xx,2}\omega^2, \text{ etc.}$$

			M_{xx}
			ωD_{xx}
			M_{xy}
			ωD_{xy}
			M_{yy}
			ωD_{yy}
			M_{yx}
			ωD_{yx}

			M_{xx}
			ωD_{xx}
			M_{xy}
			ωD_{xy}
			M_{yy}
			ωD_{yy}
			M_{yx}
			ωD_{yx}

Type 2 Bearing Data, NCAL $\geq$ 2.

Repeat the following input as many times as given by NCAL.

Speed Data (1P4E14.6)

____________________. Speed, RPM

Bearing Coefficients for Translatory Motion

(1P4E14.6)

______ ______ ______ ______ $K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}$
______ ______ ______ ______ $K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$

______ ______ ______ ______ $K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}$
______ ______ ______ ______ $K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$

Bearing Coefficients for Tilting

(1P4E14.6)

Applies only when NMOM=1. Give 2 cards per bearing, in total 2•NB cards

______ ______ ______ ______ $M_{xx}, \omega D_{xx}, M_{xy}, \omega D_{xy}$
______ ______ ______ ______ $M_{yy}, \omega D_{yy}, M_{yx}, \omega D_{yx}$

______ ______ ______ ______ $M_{xx}, \omega D_{xx}, M_{xy}, \omega D_{xy}$
______ ______ ______ ______ $M_{yy}, \omega D_{yy}, M_{yx}, \omega D_{yx}$

APPENDIX B

SAMPLE CALCULATION AND INPUT FORMS FOR THE COMPUTER PROGRAM
"THE STABILITY OF A ROTOR IN FLUID FILM BZARINGS"

```
$JOB            0,5,5000        65-341,FREEMAN,SESCD
$EXECUTE        IBJOB
$IBJOB FREMAN   MAP
$IBFTC ROTOR2   M94,XR7,NODECK
      COMMON     XC(9,30),XS(9,30),YC(9,30),YS(9,30),DMXA(30),DMYA(30),DV
     1XA(30),DVXB(30),DVXD(30),DVYA(30),DVYB(30),DVYC(30),DVYD(30),DVXC(
     230),RM(30),RL(30),RS(30),RIP(30),AN(30),BN(30),DN(30),
     3           LB(10),BKXX(10),BCXX(10),BKXY(10),BCXY(10),BKYY(10),BCYY(
     430),BKYX(10),BCYX(10),PRMS(10),BRFR(10),FRQ1(100),FREQ(110),  PMX(
     510),PMY(10),PKX(10),PCX(10),PKY(10),PCY(10),        CFM(8,8),ENT(9)
     6,CLNR(8),B2N1(8,8),B2NP(8,8),B2N2(8,8),CF9,FRW,DT,DR,DE,ENGY1,B21,
     7B2P,B22
  200 READ  (5,100)
      READ  (5,105)NS,NB,NFR,NCAL,NPST,INP
      READ  (5,103)YM
      WRITE (6,100)
      WRITE (6,108)
      WRITE (6,110)NS,NB,NFR,NCAL,NPST,INP
      WRITE (6,104)YM
      WRITE (6,111)
      WRITE (6,116)
      DO 201 J=1,NS
      READ  (5,103)RM(J),RL(J),RS(J),RIP(J)
  201 WRITE (6,114)J,RM(J),RL(J),RS(J),RIP(J)
      READ  (5,118)(LB(J),J=1,NB)
      WRITE (6,120)
      WRITE (6,118)(LB(J),J=1,NB)
      IF(NPST) 208,228,208
  208 WRITE (6,128)
      WRITE (6,127)
      DO 209 J=1,NB
      READ  (5,125)PMX(J),PKX(J),PCX(J),PMY(J),PKY(J),PCY(J)
      KST=LB(J)
  209 WRITE (6,126)KST,PMX(J),PKX(J),PCX(J),PMY(J),PKY(J),PCY(J)
  228 READ  (5,103)(FRQ1(J),J=1,NFR)
      WRITE (6,101)
      WRITE (6,103)(FRQ1(J),J=1,NFR)
C                       CONVERT INPUT UNITS
  250 AMS=1000.0
      CF1=386.069*AMS
      RS(NS)=RS(1)
      DO 251 J=1,NS
      RM(J)=RM(J)/CF1
      RIP(J)=RIP(J)/CF1
      STF=YM/AMS*RS(J)
      AN(J)=RL(J)/STF
      BN(J)=RL(J)/2.0*AN(J)
  251 DN(J)=RL(J)/3.0*BN(J)
  229 READ  (5,103)SPST,SPFN,SPINC
      WRITE (6,141)
      WRITE (6,103)SPST,SPFN,SPINC
      DO 204 J=1,NB
      KST=LB(J)
      READ  (5,103)BKXX(J),BCXX(J),BKXY(J),BCXY(J)
      READ  (5,103)BKYY(J),BCYY(J),BKYX(J),BCYX(J)
      WRITE (6,121)KST
      WRITE (6,122)
      WRITE (6,103)BKXX(J),BCXX(J),BKXY(J),BCXY(J)
      WRITE (6,123)
      WRITE (6,103)BKYY(J),BCYY(J),BKYX(J),BCYX(J)
      C1=BCXX(J)+BCYY(J)
      C1=(BKXX(J)*BCYY(J)+BKYY(J)*BCXX(J)-BKXY(J)*BCYX(J)-BKYX(J)*BCXY(J
     1))/C1
```

```
      C2=BCXX(J)*BCYY(J)-BCXY(J)*BCYX(J)
      C2=((BKXX(J)-C1)*(BKYY(J)-C1)-BKXY(J)*BKYX(J))/C2
      C4=386.069/C2*C1
      IF(C2) 206,205,205
  205 C2=SQRT(C2)
      C3=C2
      GO TO 207
  206 C3=-1.0
  207 WRITE (6,124)
      WRITE (6,103)C2,C1,C4
      PRMS(J)=C4
      DVXA(J)=C3
  204 BRFR(J)=C3
      MFR=1
      MBR=0
  214 KST=0
      MBR=MBR+1
      FRW=FRQ1(MFR)
      DO 213 J=1,NB
      C1=DVXA(J)
      IF(C1) 213,213,210
  210 IF(C1-FRW) 213,212,211
  211 FRW=C1
      MFR=MFR-1
  212 KST=J
  213 CONTINUE
      IF(KST) 216,216,215
  215 DVXA(KST)=-1.0
  216 FREQ(MBR)=FRW
      IF(MFR) 217,218,218
  217 MFR=0
  218 MFR=MFR+1
      IF(MFR-NFR) 214,214,219
  219 C2=-0.6
      KST=0
      DO 222 J=1,NB
      C1=DVXA(J)
      IF(C1) 222,222,220
  220 IF(C1-C2) 222,222,221
  221 C2=C1
      KST=J
  222 CONTINUE
      IF(KST) 224,224,223
  223 MBR=MBR+1
      FREQ(MBR)=C2
      DVXA(KST)=-1.0
      GO TO 219
  224 NFR1=MBR
      SPCAL=SPST
  225 WRITE (6,146)SPCAL
      ANSPR=0.10471976*SPCAL
      C2=ANSPR*ANSPR
      WRITE (6,148)
      DO 226 J=1,NB
      KST=LB(J)
      C1=PRMS(J)/C2
      C3=BRFR(J)*SPCAL
  226 WRITE (6,117)KST,C3,C1
      WRITE (6,147)
      KDC=0
      MFR=1
C                      FREQUENCY DEPENDENT PARAMETERS
  300 FRW=FREQ(MFR)
```

```
      ANSP=ANSPR*FRW
      ANSP2=ANSP*ANSP
      DO 301 J=1,NS
      STF=RIP(J)*ANSP2
      DMXA(J)=STF
      DMYA(J)=STF
      STF=RY(J)*ANSP2
      DVXA(J)=STF
      DVYA(J)=STF
      DVXB(J)=0.0
      DVXC(J)=0.0
      DVXD(J)=0.0
      DVYB(J)=0.0
      DVYC(J)=0.0
  301 DVYD(J)=0.0
  302 DO 311 J=1,NB
      KST=LB(J)
      CF1K=BKXX(J)
      CF1C=BCXX(J)*FRW
      CF1D=BKXY(J)
      CF1E=BCXY(J)*FRW
      CF2K=BKYY(J)
      CF2C=BCYY(J)*FRW
      CF2D=BKYX(J)
      CF2E=BCYX(J)*FRW
      IF(NPST) 303,306,303
  303 CF1M=PKX(J)-PMX(J)/386.069*ANSP2
      CF1N=PCX(J)*ANSP
      CF1A=CF1K+CF1M
      CF1B=CF1C+CF1N
      CF2M=PKY(J)-PMY(J)/386.069*ANSP2
      CF2N=PCY(J)*ANSP
      CF2A=CF2K+CF2M
      CF2B=CF2C+CF2N
      GO TO 307
  306 CF1=CF1K
      CF2=CF1C
      CF3=CF1D
      CF4=CF1E
      CF5=CF2D
      CF6=CF2E
      CF7=CF2K
      CF8=CF2C
      GO TO 308
  307 CF4=CF2A*CF2A+CF2B*CF2B
      CF1=(CF2A*CF2D+CF2B*CF2E)/CF4
      CF2=(CF2A*CF2E-CF2B*CF2D)/CF4
      CF3=(CF2A*CF2M+CF2B*CF2N)/CF4
      CF4=(CF2A*CF2N-CF2B*CF2M)/CF4
      CF5=CF1A-CF1*CF1D+CF2*CF1E
      CF6=CF1B-CF2*CF1D-CF1*CF1E
      CF7=-CF3*CF1D+CF4*CF1E
      CF8=-CF4*CF1D-CF3*CF1E
      CF2N=CF5*CF5+CF6*CF6
      CF2A=(CF5*CF1M+CF6*CF1N)/CF2N
      CF2B=(CF5*CF1N-CF6*CF1M)/CF2N
      CF2M=(CF5*CF7+CF6*CF8)/CF2N
      CF2N=(CF5*CF8-CF6*CF7)/CF2N
      CF1A=-CF1*CF2A+CF2*CF2B
      CF1B=CF1*CF2B+CF2*CF2A
      CF1M=CF3-CF1*CF2M+CF2*CF2N
      CF1N=CF4-CF1*CF2N-CF2*CF2M
      CF1=CF1K*CF2A-CF1C*CF2B+CF1D*CF1A+CF1E*CF1B
```

```
      CF2=CF1K*CF2B+CF1C*CF2A-CF1D*CF1B+CF1E*CF1A
      CF3=CF1K*CF2M-CF1C*CF2N+CF1D*CF1M-CF1E*CF1N
      CF4=CF1K*CF2N+CF1C*CF2M+CF1D*CF1N+CF1E*CF1M
      CF5=CF2D*CF2A-CF2E*CF2B+CF2K*CF1A+CF2C*CF1B
      CF6=CF2D*CF2B+CF2E*CF2A-CF2K*CF1B+CF2C*CF1A
      CF7=CF2D*CF2M-CF2E*CF2N+CF2K*CF1M-CF2C*CF1N
      CF8=CF2D*CF2N+CF2E*CF2M+CF2K*CF1N+CF2C*CF1M
  308 DVXA(KST)=DVXA(KST)-CF1/AMS
      DVXB(KST)=CF2/AMS
      DVXC(KST)=CF3/AMS
      DVXD(KST)=CF4/AMS
      DVYA(KST)=DVYA(KST)-CF7/AMS
      DVYB(KST)=CF8/AMS
      DVYC(KST)=CF5/AMS
      DVYD(KST)=CF6/AMS
  311 CONTINUE
C                      ROTOR CALCULATION
      DO 428 I=1,8
      KST=I
      BMXC=0.0
      BMXS=0.0
      BMYC=0.0
      BMYS=0.0
      VXC=0.0
      VXS=0.0
      VYC=0.0
      VYS=0.0
      XC(I,1)=0.0
      XS(I,1)=0.0
      YC(I,1)=0.0
      YS(I,1)=0.0
      DXC=0.0
      DXS=0.0
      DYC=0.0
      DYS=0.0
      GO TO (407,408,409,410,412,413,414,415)          ,KST
  407 DXC=1.0
      GO TO 418
  408 DXS=1.0
      GO TO 418
  409 DYC=1.0
      GO TO 418
  410 DYS=1.0
      GO TO 418
  412 XC(5,1)=1.0
      GO TO 418
  413 XS(6,1)=1.0
      GO TO 418
  414 YC(7,1)=1.0
      GO TO 418
  415 YS(8,1)=1.0
  418 DO 424 J=1,NS
      BMXC=BMXC+DMXA(J)*DXC
      BMXS=BMXS+DMXA(J)*DXS
      BMYC=BMYC+DMYA(J)*DYC
      BMYS=BMYS+DMYA(J)*DYS
      C1=DVXA(J)*XC(I,J)-DVXB(J)*XS(I,J)-DVXC(J)*YC(I,J)-DVXD(J)*YS(I,J)
      C2=DVXB(J)*XC(I,J)+DVXA(J)*XS(I,J)+DVXD(J)*YC(I,J)-DVXC(J)*YS(I,J)
      C3=-DVYC(J)*XC(I,J)-DVYD(J)*XS(I,J)+DVYA(J)*YC(I,J)-DVYB(J)*YS(I,J
     1)
      C4=DVYD(J)*XC(I,J)-DVYC(J)*XS(I,J)+DVYB(J)*YC(I,J)+DVYA(J)*YS(I,J)
      VXC=VXC+C1
      VXS=VXS+C2
```

```
      VYC=VYC+C3
      VYS=VYS+C4
  422 IF(NS-J) 424,424,423
  423 XC(I,J+1)=XC(I,J)+RL(J)*DXC     +BN(J)*BMXC       +DN(J)*VXC
      XS(I,J+1)=XS(I,J)+RL(J)*DXS     +BN(J)*BMXS       +DN(J)*VXS
      YC(I,J+1)=YC(I,J)+RL(J)*DYC     +BN(J)*BMYC       +DN(J)*VYC
      YS(I,J+1)=YS(I,J)+RL(J)*DYS     +BN(J)*BMYS       +DN(J)*VYS
      DXC=DXC+AN(J)*BMXC+BN(J)*VXC
      DXS=DXS+AN(J)*BMXS+BN(J)*VXS
      DYC=DYC+AN(J)*BMYC+BN(J)*VYC
      DYS=DYS+AN(J)*BMYS+BN(J)*VYS
      BMXC=BMXC+RL(J)*VXC
      BMXS=BMXS+RL(J)*VXS
      BMYC=BMYC+RL(J)*VYC
      BMYS=BMYS+RL(J)*VYS
  424 CONTINUE
      CFM(1,I)=BMXC
      CFM(2,I)=BMXS
      CFM(3,I)=BMYC
      CFM(4,I)=BMYS
      CFM(5,I)=VXC
      CFM(6,I)=VXS
      CFM(7,I)=VYC
      CFM(8,I)=VYS
  428 CONTINUE
      CALL EQS
  506 MFR=MFR+1
      IF(MFR-NFR1) 300,300,507
C               ADVANCE SPEED
  507 SPCAL=SPCAL+SPINC
      IF(SPFN-SPCAL) 511,225,225
C               PROGRAM END
  511 KDC=KDC+1
      IF(NCAL-KDC) 510,510,229
  510 IF(INP) 509,200,509
  509 STOP
  100 FORMAT(49H0                                                  )
  101 FORMAT(17H0FREQUENCY RATIOS)
  103 FORMAT(4(1XE13.6))
  104 FORMAT(16H0YOUNGS MODULUS=, E14.7)
  105 FORMAT(7I5)
  108 FORMAT(58H0  STATIONS  NO.BRGS.  NO.FREQ  NO.SPEED PED.FLEX     I
     1NP)
  110 FORMAT(4XI4,6(6XI4))
  111 FORMAT(14H0   ROTOR DATA)
  114 FORMAT(4XI4,7XE13.6,1XE13.6,1XE13.6,1XE13.6)
  116 FORMAT(67H  STATION NO.        MASS            LENGTH    CRO.SECT.INER
     1T   (IP-IT))
  117 FORMAT(4XI4,7XE13.6,1XE13.6)
  118 FORMAT(10(1XI4))
  120 FORMAT(18H0BEARING STATIONS )
  121 FORMAT(24H0 BEARING AT STATION NO.,I3)
  122 FORMAT(52H0       KXX            WCXX            KXY           WCXY)
  123 FORMAT(52H0       KYY            WCYY            KYX           WCYX)
  124 FORMAT(43H0 INST.FREQ.RT MASS*(FREQ)**2 WEIGHT*(W)**2)
  125 FORMAT(6(1XE11.4))
  126 FORMAT(1XI4,4XE11.4,1XE11.4,1XE11.4,1XE11.4,1XE11.4,1XE11.4)
  127 FORMAT(76H0 BRG.ST. MASS.X-DIR.       KX             CX       MASS.Y-DIR
     1.      KY          CY)
  128 FORMAT(15H0 PEDESTAL DATA)
  141 FORMAT(42H0INITIAL SPEED    FINAL SPEED    SPEED INCR.)
  146 FORMAT(13H1ROTOR SPEED=, E13.6,3HRPM)
  147 FORMAT(64H0    FREQ.RAT.     DETERMINANT     RE(DET)         IM(DET)
```

```
     1      ENERGY   )
  148 FORMAT(42H0 BRG,STATION   INST,FREQ,RPM   INST,WEIGHT)
      END
$IBFTC SEQS     M94,XR7
      SUBROUTINE     EQS
      COMMON    XC(9,30),XS(9,30),YC(9,30),YS(9,30),DMXA(30),DMYA(30),DV
     1XA(30),DVXB(30),DVXD(30),DVYA(30),DVYB(30),DVYC(30),DVYD(30),DVXC(
     230),RM(30),RL(30),RS(30),RIP(30),AN(30),BN(30),DN(30),
     3          LB(10),BKXX(10),BCXX(10),BKXY(10),BCXY(10),BKYY(10),BCYY(
     430),BKYX(10),BCYX(10),PRMS(10),BRFR(10),FRGI(100),FREQ(110),  PMX(
     510),PMY(10),PKX(10),PCX(10),PKY(10),PCY(10),       CFM(8,8),ENT(9)
     6,CLNR(8),B2N1(8,8),B2NP(8,8),B2N2(8,8),CF9,FRW,DT,DR,DE,ENGY1,B21,
     7B2P,B22
      PRN3=1.0
      DO 850 I=1,8
      ENT(I)=0.0
      DO 850 J=1,8
  850 B2N1(I,J)=CFM(I,J)
      CALL MATINV(B2N1,8,ENT,1,DT)
      DT=SQRT(PRN3*DT)
      MD=7
      DR=CFM(1,1)
      DE=CFM(1,2)
  851 DO 853 I=1,MD
      DO 852 J=1,MD
      B2N1(I,J)=CFM(I,J)
      B2NP(I,J)=CFM(I,J)
  852 B2N2(I,J)=CFM(I,J)
  853 B2NP(I,MD)=CFM(I,MD+1)
      CALL MATINV(B2N1,MD,ENT,1,B21)
      CALL MATINV(B2NP,MD,ENT,1,B2P)
      IF(MD-7) 855,854,854
  854 ENGY1=3.1415927*B2P
  855 MD=MD-1
      CALL MATINV(B2N2,MD,ENT,1,B22)
      B21=B21/B22
      B2P=B2P/B22
      C1=B21*DR-B2P*DE
      DE=B21*DE+B2P*DR
      DR=C1
      MD=MD-1
      IF(MD-3) 856,851,851
  856 WRITE (6,880)FRW,DT,DR,DE,ENGY1
      RETURN
  880 FORMAT(5(1XE13.6))
      END
$IBFTC SMATIN  M94,XR7
      SUBROUTINE MATINV (A,N,B,M,DETER)
C     MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
      DIMENSION A(8,8   ),B(9  ),IPIVO(9  ),PIVOT(9 )
      DETER =1.0
      DO 17 J=1,N
      KC=0
      KR=0
      DO 14 I=1,N
      IF(A(I,J)) 11,12,11
   11 KC=1
   12 IF(A(J,I)) 13,14,13
   13 KR=1
   14 CONTINUE
      IF(KC) 15,16,15
   15 IF(KR) 17,16,17
   16 DETER=0.0
```

```
      GO TO 600
   17 CONTINUE
      DO 20 J=1,N
   20 IPIVO(J)=0
      DO 550 I=1,N
C
C     SEARCH FOR PIVOT ELEMENT
C
      AMAX=0.0
      DO 105 J=1,N
      IF (IPIVO(J)-1) 60,105,60
   60 DO 100 K=1,N
      IF (IPIVO(K) -1) 80, 100, 600
   80 IF (ABS(AMAX)-ABS(A(J,K))) 85,100,100
   85 IROW=J
      ICOLU =K
      AMAX=A(J,K)
  100 CONTINUE
  105 CONTINUE
      IPIVO(ICOLU)=IPIVO(ICOLU)+1
C
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
      IF (IROW-ICOLU)  140, 260, 140
  140 DETER =-DETER
      DO 200 L=1,N
      AMAX=A(IROW,L)
      A(IROW,L)=A(ICOLU,L)
  200 A(ICOLU,L)=AMAX
      AMAX=B(IROW)
      B(IROW)=B(ICOLU)
      B(ICOLU)=AMAX
  260 PIVOT(I)=A(ICOLU,ICOLU)
      DETER =DETER*PIVOT(I)
C
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
      A(ICOLU,ICOLU)=1.0
      DO 350 L=1,N
  350 A(ICOLU,L)=A(ICOLU,L)/PIVOT(I)
      B(ICOLU)=B(ICOLU)/PIVOT(I)
C
C     REDUCE NON-PIVOT ROWS
C
  380 DO 550 L1=1,N
      IF(L1-ICOLU)  400, 550, 400
  400 AMAX=A(L1,ICOLU)
      A(L1,ICOLU) =0.0
      DO 450 L=1,N
  450 A(L1,L)=A(L1,L)-A(ICOLU,L)*AMAX
      B(L1)=B(L1)-B(ICOLU)*AMAX
  550 CONTINUE
  600 RETURN
      END
      END OF FILE
```

```
TEST CASE 1. UNSYMMETRICAL ROTOR
   9     2     4     1     0     1
0.3000000E+08
  0.162000E+02  0.370000E+01  0.695000E+01  0.114200E+03
  0.391000E+02  0.775000E+01  0.105100E+02  0.254000E+03
  0.227000E+02  0.830000E+01  0.836000E+01  0.000000E+00
  0.121000E+02  0.615000E+01  0.695000E+01  0.000000E+00
  0.391000E+02  0.104000E+02  0.105100E+02  0.254000E+03
  0.563000E+02  0.665000E+01  0.669000E+01  0.583000E+03
  0.378000E+02  0.575000E+01  0.695000E+01  0.000000E+00
  0.127000E+02  0.425000E+01  0.695000E+01  0.000000E+00
  0.212000E+02  0.000000E+00  0.000000E+00  0.166000E+03
   2     8
  0.500000E+00  0.495000E+00  0.490000E+00  0.480000E+00
  0.835000E+04  0.850000E+04  0.500000E+02
  0.128340E+06  0.130350E+07  0.619710E+06  0.118230E+06
  0.108760E+06  0.181920E+06 -0.884860E+05  0.118230E+06
  0.478420E+06  0.773830E+06  0.332950E+06  0.158120E+06
  0.124770E+06  0.924700E+05  0.109000E+05  0.157820E+06
-       END OF FILE
-       END OF FILE
```

```
FREMAN
                                                                              08/12/65

 21. .IOCSM  22046        .TCHEX  22042      .BASID  22045 .
 22. //       73440

 I/O BUFFERS
                                        22046 THRU  73371

 UNUSED CORE
 TEST CASE 1, UNSYMMETRICAL ROTOR       73372 THRU  73437

   STATIONS  NO.BRGS.  NO.FREQ   NO.SPEED PED.FLEX     INP
      9         2         4          1        0          1

 YOUNGS MODULUS= 0.3000000E 08

   ROTOR DATA
 STATION NO.
                  MASS          LENGTH      CRO.SECT.INERT    (IP-IT)
      1       0.162000E 02  0.370000E 01  0.695000E 01  0.114200E 03
      2       0.391000E 02  0.775000E 01  0.105100E 02  0.254000E 03
      3       0.227000E 02  0.830000E 01  0.838000E 01  0.
      4       0.121000E 02  0.615000E 01  0.695000E 01  0.
      5       0.391000E 02  0.104000E 02  0.105100E 02  0.254000E 03
      6       0.563000E 02  0.865000E 01  0.869000E 01  0.583000E 03
      7       0.378000E 02  0.575000E 01  0.695000E 01  0.
      8       0.127000E 02  0.425000E 01  0.695000E 01  0.
      9       0.212000E 02  0.            0.            0.166000E 03

 BEARING STATIONS
   2    8

 FREQUENCY RATIOS
  0.500000E 00  0.495000E-00  0.490000E-00  0.480000E-00

 INITIAL SPEED   FINAL SPEED    SPEED INCR.
  0.835000E 04  0.850000E 04  0.500000E 02

 BEARING AT STATION NO.  2

      KXX           WCXX          KXY           WCXY
 0.128040E 06  0.130350E 07  0.619710E 06  0.118230E 06

      KYY           WCYY          KYX           WCYX
 0.108760E 06  0.181920E 06 -0.884860E 05  0.118230E 06

 INST.FREQ.RT MASS*(FREQ)**2 WEIGHT*(W)**2
 0.506281E 00  0.688392E 05  0.103665E 09

 BEARING AT STATION NO.  8

      KXX           WCXX          KXY           WCXY
 0.478420E 06  0.773830E 06  0.332950E 06  0.158120E 06

      KYY           WCYY          KYX           WCYX
 0.124770E 06  0.924700E 05  0.109000E 05  0.157820E 06

 INST.FREQ.RT MASS*(FREQ)**2 WEIGHT*(W)**2
 0.352643E-00  0.998737E 05  0.310059E 09
```

ROTOR SPEED= 0.835000E 04RPM

BRG.STATION	INST.FREQ.RPM	INST.WEIGHT
2	0.422745E 04	0.135609E 03
8	0.294457E 04	0.405522E 03

FREQ.RAT.	DETERMINANT	RE(DET)	IM(DET)	ENERGY
0.506281E 00	0.244251E 15	0.755700E 14	-0.232267E 15	-0.299044E 28
0.500000E 00	0.124160E 15	0.342078E 14	-0.119364E 15	-0.161673E 24
0.495000E-00	0.218870E 14	0.660811E 13	-0.208653E 14	-0.257902E 27
0.490000E-00	0.865557E 14	-0.158965E 14	0.450835E 14	0.130422E 28
0.480000E-00	0.321630E 15	-0.443312E 14	0.318530E 15	0.491536E 28
0.352643E-00	0.528277E 16	0.223315E 16	0.478546E 16	0.145530E 29

ROTOR SPEED= 0.840000E 04RPM

BRG.STATION	INST.FREQ.RPM	INST.WEIGHT
2	0.425276E 04	0.133999E 03
8	0.296220E 04	0.400709E 03

FREQ.RAT.	DETERMINANT	RE(DET)	IM(DET)	ENERGY
0.506281E 00	0.283196E 15	0.105908E 15	-0.262647E 15	-0.283772E 28
0.500000E 00	0.166938E 15	0.637894E 14	-0.154270E 15	-0.157593E 28
0.495000E-00	0.590471E 14	0.354134E 14	-0.592738E 14	-0.296435E 27
0.490000E-00	0.448993E 14	0.119875E 14	0.432693E 14	0.119572E 28
0.480000E-00	0.270884E 15	-0.185800E 14	0.270239E 15	0.469746E 28
0.352643E-00	0.520152E 16	0.221611E 16	0.470581E 16	0.157555E 29

ROTOR SPEED= [illegible] 04RPM

ANG.STATION	INIT.FREQ.(CPM)	LAST.WEIGHT
2	0.4279070E 04	0.1326180E 01
[illegible]	0.2373540E 04	0.3959610E 03

FREQ.(CAL.)	DETERMINANT	RESID.(?)	INDEX	ENERGY
0.5062940E 00	0.3212970E 15	0.1332260E 15	-0.2914555E 15	-0.2679858E 24
0.5000000E 00	0.2091300E 15	0.1243260E 14	-0.1475150E 15	-0.1531060E 24
0.4950000E-00	0.1151350E 15	0.6335390E 14	-0.7613910E 14	-0.3321320E 27
0.4900000E-0[illegible]	[illegible] 14	0.3907680E 14	0.2083650E 13	0.1089630E 28
0.4900000E-0[illegible]	0.2735120E 15	0.6279030E 13	0.2234240E 15	0.4476860E 24
0.3520400E-0[illegible]	[illegible] 16	0.2104[illegible] 16	0.4425530E 16	0.1641980E 24

ROTOR SPEED= 0.850000E 04RPM

BRG.STATION	INST.FREQ.RPM	INST.WEIGHT
2	0.430339E 04	0.130865E 03
8	0.299747E 04	0.391336E 03

FREQ.RAT.	DETERMINANT	RE(DET)	IM(DET)	ENERGY
0.506281E 00	0.358201E 15	0.163515E 15	-0.318702E 15	-0.251727E 28
0.500000E 00	0.250151E 15	0.120144E 15	-0.219410E 15	-0.148224E 28
0.495000E-00	0.159558E 15	0.904240E 14	-0.131462E 15	-0.364940E 27
0.490000E-00	0.745147E 14	0.653618E 14	-0.357811E 14	0.982928E 27
0.480000E-00	0.180697E 15	0.306025E 14	0.178086E 15	0.425403E 28
0.352643E-00	0.503972E 16	0.217208E 16	0.454762E 16	0.180460E 29

INPUT FOR PN0017:

STABILITY OF A FLEXIBLE ROTOR IN FLUID FILM BEARINGS

Card 1 Text Col. 2-49

Card 2 (6I5)

______ 1. NS Number of rotor mass stations ($\leq$ 30)

______ 2. NB Number of bearings ($\leq$ 10)

______ 3. NFR Number of frequency ratios ($\leq$ 100)

______ 4. NCAL Number of rotor speeds

______ 5. NPST 0: Rigid Pedestal 1: Flexible pedestal

______ 6. 0: more input follows 1: last set of input

Card 3 (1XE13.6)

__________________________ 1. E, Youngs modulus, lbs/in^2

ROTOR DATA

FORMAT (4(1XE13.6))

Give one card for each rotor station, in total NS cards

Rotor Station (don't punch)	Station Mass lbs.	Length of Shaft Sec inch	Cross sectional Moment of Inertia, in^4	Polar-Transve Mass Moment of Inertia $lbs.in^2$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Rotor Stations with Bearing Support

(10(1XI4))

Give NB items

Pedestal Data

(6(1XE11.4))

Applies only when NPST = 1. Give one card for each bearing, in total NB cards.

Pedes.Mass x-direction lbs.	Pedes.Stiffn. x-direction lbs/in	Pedes.Damping x-direction lbs.sec/in	Pedes.Mass. y-direction lbs.	Pedes.Stiffn. y-direction lbs./in	Pedes.Damping y-direction lbs.sec/in

FREQUENCY RATIO VALUES

(4(1XE13.6))

Applies only when NFR $\geq$ 1. List as many values as given by NFR, 4 values per card.

BEARING DATA

Repeat the following input as many times as given by NCAL

Speed Data (4(1XE13.6))

______________________________ 1. Initial Speed, RPM

______________________________ 2. Final Speed, RPM

______________________________ 3. Speed Increment, RPM

Bearing Coefficients

(4(1XE13.6))

Give 2 cards per bearing with 4 coefficients per card, in total 2 NB Cards

________	________	________	________	$K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}$
________	________	________	________	$K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$
________	________	________	________	$K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}$
________	________	________	________	$K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$

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13. ABSTRACT

This report is a manual for using the two computer programs:

1. "Unbalance Response of a Rotor in Fluid Film Bearings."

2. "The Stability of a Rotor in Fluid Film Bearings."

The report gives the analysis on which the programs are based, and the instructions for preparing the computer input and for interpreting the computer output.

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KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Bearings						
Lubrication						
Fluid Film						
Hydrodynamic						
Hydrostatic						
Rotor-Bearing Dynamics						
Stability						
Critical Speed						
Laminar Film						
Turbulent film						

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